

BBC

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How one experiment could rewrite the laws of physics



Walking With Dinosaurs 3D

How science brought new giants to life

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Why craving coffee makes you an addict

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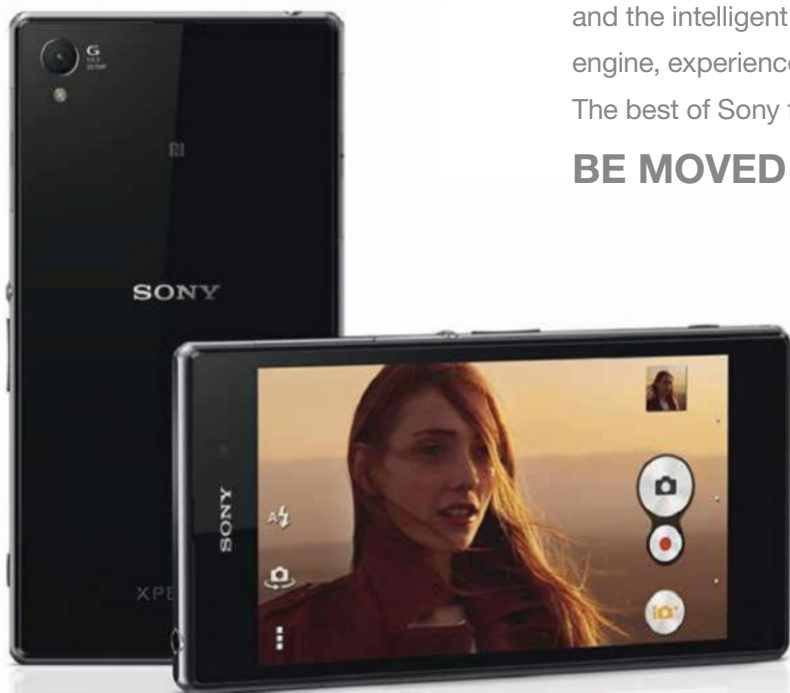
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WELCOME TO FOCUS



YOU NEVER FORGET your first Doctor Who. Mine was the legendary Tom Baker – he of the unruly hair, multicoloured scarf and robot dog, K-9. Amazingly, the Doctor first materialised on our screens 50 years ago this month, so we decided to take a look at which of the show's ideas have become science fact. On p47, bestselling writer and *Who* fan Brian Clegg journeys back in time.

And there's more *Doctor Who* science on BBC TV this month courtesy of another well-known Brian, Prof Cox.

Talking of science fiction ideas, we've all seen antigravity in the movies. But now scientists at CERN (home of the Large Hadron Collider) have started experiments to discover if such a force really exists in nature. So could we soon be riding *Back To The Future*-style hoverboards? Turn to p68 to find out.

I'm writing this page early in the morning on a strong cup of coffee. But is that such a good idea? Some of the *BBC Focus* team are heavy tea and coffee drinkers, so we decided to find out what science has to say about caffeine. In particular, how much is too much? Emma Davies has the answers on p37.

And finally, it's that time of year! You'll find a festive edition of Q&A on p87, our pick of great Christmas books on p139 and a review of the latest and greatest tablet computers on p121.

Enjoy!

P.S.
Don't miss our January issue, on sale 12 December

Graham

Graham Southorn, Editor

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APPEARING IN THIS ISSUE...



Brian Clegg

The popular science writer and *Doctor Who* fan is the author of *Build Your Own Time Machine* and *Dice World: Science And Life In A Random Universe*. He investigates the science of time travel, regeneration, Daleks and sonic screwdrivers on p47.



Emma Davies

Emma has a PhD in food science and is a former features editor of *Chemistry World*. She puts her background to good use in this month's issue as she investigates whether caffeine is bad for you (p37) and asks: how much is too much?



Cherry Lewis

Dr Cherry Lewis is an honorary Research Fellow in the School of Earth Sciences at the University of Bristol and is the author of *The Dating Game: One Man's Search For The Age Of The Earth*. She uncovers the fascinating history of isotopes on p124.



Paul Parsons

The former editor of this magazine finished his academic career researching theoretical cosmology. This month, on p68, he looks at one of the most mind-bending of topics: the quest to discover antigravity.



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On p34 **Adam Hart**, presenter of BBC TV's *Planet Ant*, answers questions on the frontiers of entomology

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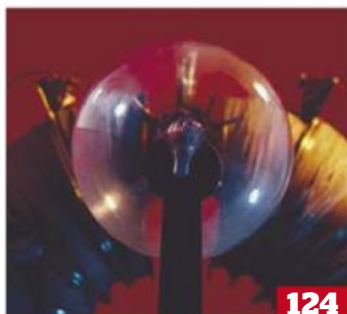
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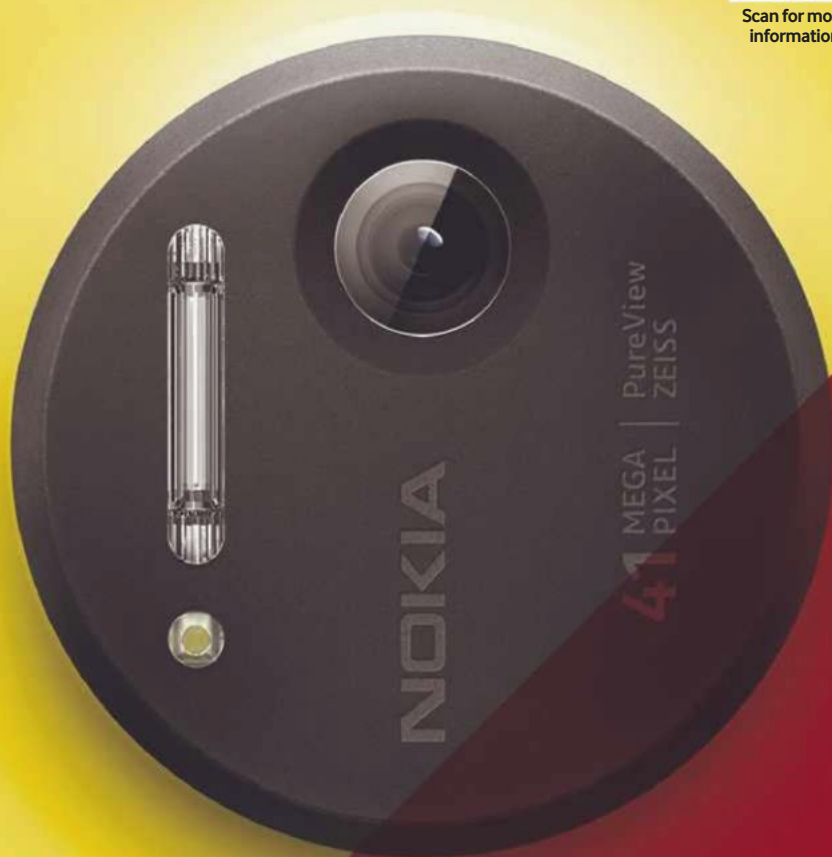
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White out

THIS IS THE Rhone Glacier, primary contributor to Lake Geneva and source of the Rhone River. The white blankets seen in the foreground have been placed there by local business owners in an attempt to preserve their glacier-reliant tourist attraction – an ice tunnel.

The tunnel is under threat because the glacier is melting. It is believed that 8,000 years ago the Rhone Glacier was the largest in Europe, reaching all the way to Lyon, France. Now, there is a mere 9.6km (6 miles) of ice left.

“These blankets mask the ice from sunlight, just like being under a parasol,” explains Dr Jez Everest of the Iceland Glacier Observatory, who is not involved with the tunnel preservation attempt. “It will work both by blocking solar radiation, which causes direct heating of the ice, and also by allowing an air gap to exist between the blankets and parts of the glacier, creating a cooler air barrier that slows the melting of the ice surface.”

PHOTO: MARTIN VAN DUIN





MegaPixel

Copper load of that

INSIDE THE BELLY of this copper-plated beast, atoms are accelerated up to 20 per cent of the speed of light (60,000km/s). Situated at the GSI Helmholtz Centre for Heavy Ion Research near Darmstadt, Germany, the 120m-long UNILAC (Universal Linear Accelerator) is used to accelerate ions – charged atoms or molecules – so that they can be smashed into targets, creating brand new elements.

“The ions shoot through the cylindrical structures that are hanging from the top of the accelerator,” says Professor Christoph Düllmann at GSI. “Each time an ion exits one of the cylinders, it picks up a little more energy and becomes a little bit faster.”

Earlier this year, the accelerator was used to create a synthetic material called element 115 – so new it hasn’t been officially named – by directing calcium ions at a thin film of the element americium. Similar experiments have allowed GSI scientists to discover six other elements, including hassium, bohrium and copernicium.

PHOTO: G OTTO/GSI





MegaPixel

Slimy swimming

YOU COULD BE forgiven for mistaking this plush green blanket for a golf course. In fact, it is China's largest ever algae bloom, which took place in July. The phenomenon has become something of a tourist attraction, with visitors bathing in the green growth.

An influx of *Enteromorpha prolifera* algae occurs every summer, but the amount produced this year was exceptional, covering an area of 28,000km². "There could be several causes of this," says Dr Michele Stanley, an algae specialist at the Scottish Marine Institute. "Nitrate and phosphate run-off from agriculture is likely to play a part, as is increased

water temperature. Some people have also blamed the seaweed industry. Further up the coast *E. prolifera* invades seaweed farms and the farmers just throw it into the sea."

Whatever the reason for the prolific bloom, Chinese officials duly set about removing the algae. Once collected, it was sent to processing plants that transform it into animal feed, medicinal supplements and fertiliser.

E. prolifera is not toxic to humans – some areas in south China even enjoy the green growth known as sea lettuce as a delicacy, frying it up with peanuts.

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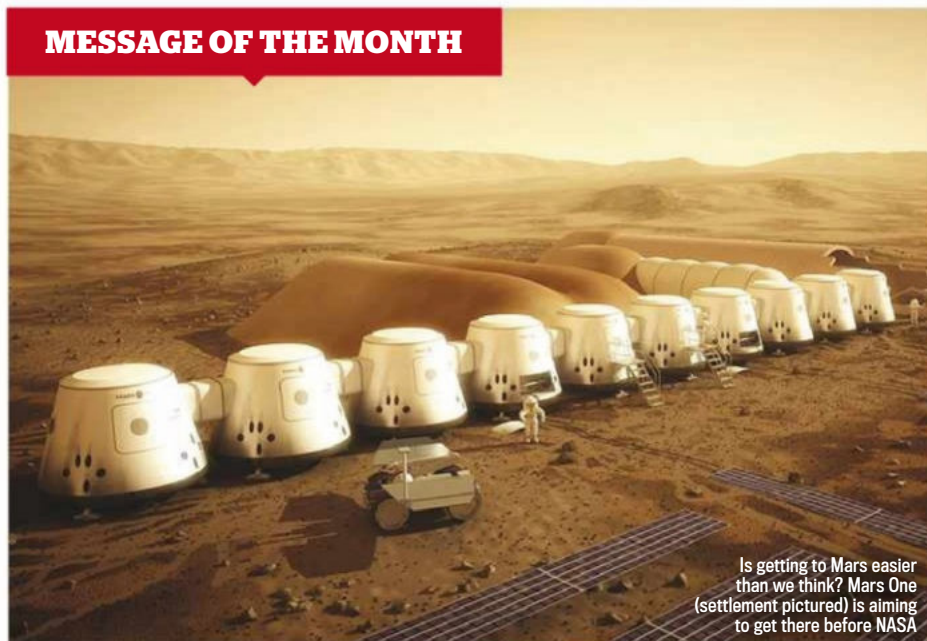
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MESSAGE OF THE MONTH



Is getting to Mars easier than we think? Mars One (settlement pictured) is aiming to get there before NASA

Mission to Mars

We can put several hundred men and women in a submarine, powered by a nuclear reactor, that does not need to surface for many months as it recycles its own oxygen and must be able to sustain its food supply. So why can we not transfer this technology to space travel? The only major difference is radiation from the Sun, but surely lead-lining and electromagnetically polarising the hull would stop most of this. As for losing muscle mass, using magnetic boots and/or spinning the ship once it gets underway with booster jets would minimise these problems.

Am I being too simplistic or are scientists not always the right people to develop this sort of technology, as they seem to think too much rather than just attacking a problem

practically? Perhaps submarine designers should be employed to add their extensive knowledge and perhaps make the whole problem a little simpler?

Charlie Frost, Wales

One of the biggest barriers is psychological. On a mission, submariners have an important job to do, comprising many different tasks. In contrast, Mars astronauts would need to build structure and purpose into their days. I'm sure the main drawback is not the spacecraft technology, which could be developed, but the cost. Mars One (www.mars-one.com) is a proposed private mission to visit the Red Planet by 2023. It seems rather ambitious to me, however. – Ed

Science of extinction

Focus seems to look at discoveries, experiments and inventions for the future but where is the coverage of what is happening here and now to the world's endangered species? The rhino is on the verge of becoming extinct in the wild as the battle to stop the poachers is already lost. Elephants and tigers will follow as countries such as China and Vietnam will eventually run out of rhino horn for their so-called medicines, and turn to other animals for their bones or tusks. The future is very bleak for all the big wild animals, and in the future generations will only see them in books, zoos or safari parks.

Surely this area of science should not be ignored, even if there is no solution?

Tony Hrizenko

It is indeed a sad story. Science may help by preserving extinct animals' DNA, but it seems depressingly futile when habitat loss is still going on. There will be no 'wild' for captive animals to return to if some people can't mend their ways. – Ed

Missing malaria

In Adam Rutherford's article on synthetic biology breakthroughs that will change the world (October, p53), you published a photo of a blood film with a caption stating that it shows blood cells infected with malarial parasites. But there are no parasites here. Instead, the blood film shows nucleated red blood cells, some immature neutrophils, metamyelocytes, myelocytes and other possibly erythroid precursors, along with the red blood cells and platelets. Perhaps a nice clear photo of a blood film with *Plasmodium falciparum*-infected red cells could adorn your magazine?

Simon Wallis, Medway Maritime Hospital

Just for you, Simon... – Ed

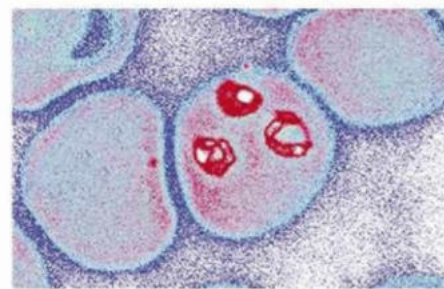


PHOTO: MARS ONE/BRYAN VERSTEEG, ALAMY

Write in and win!

The writer of next issue's Message of the Month wins a Sphero 2.0 worth £99.99. Sphero is a robotic gaming ball you control with your smartphone or tablet. It connects via Bluetooth, is waterproof and even changes colour to suit your mood.
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Fast train to Sydney

Your report on the Hyperloop proposal (October, p72) fails to mention an interesting property. The time of flight happens to be the same (about 30 minutes) for all tubes joining any two points on the Earth's surface. So, time-wise, commuting to Sydney would be as easy as getting to your nearest town.

Thomas Willetts, Cheshire

This is the 'gravity train' first proposed by Robert Hooke in the 17th Century. Speed aside, gravity trains have a big advantage: they'll only need planning permission for a large hole at either end. – Ed

A weighty question

Helen Czerski's article on the changing metal content of our coinage raises a question. When I visit the bank with bags of change, they are not counted but weighed. Surely if a pre-1992 penny is made of bronze and post-1992 models of copper-coated steel, 100 of one type would weigh more than the other, and a mixture somewhere between the two?

Kevin Wright, Harlow, Essex



Helen Czerski replies: Pre-1992 pennies are fairly rare – I found only two out of about 50 coins. And the pre-1992 ones are clearly thinner, so maybe they still have the same mass. In that case, weighing would still give you the right number.

Before the Big Bang

In your October edition, the article about the Universe (p36) states that time and space began with the Big Bang, but this cannot be true. There must have been time, because without time there could not have been an event called the Big Bang, and as time already existed, then so must space have also existed, just not as we know it!

Spencer Mather, Great Yarmouth

At the Big Bang, time is zero. But if there was a universe before ours, time would have run backwards in it. – Ed

YOUR COMMENTS ON TWITTER & FACEBOOK

We asked: **How will the human race evolve?**

@lawrence_a_penn The human eye will develop a filter to improve the appearance of everyone. Worked for Instagram

@MikeStewart75 That's called beer

@lawrence_a_penn A very well proven method – might be why we aren't evolving. Ruining natural selection

Kevin Walsh We will evolve bigger eyes and the ability to process more information in a quicker way. Also we will probably lose some strength in the legs and arms as we do less and less physical activity.

Tomo Hawk Evolve the ability to use wi-fi in our heads.

Zayn Khalil Hussain We will have extra long thumbs from stretching across our bigger smartphones!

Mark Andrew Reduced physical abilities due to our increased reliance on technology. Dumbing down of the general population since all information (correct or not) will be immediately available via the web.

Focus Magazine It might work the other way round – if all information is online, perhaps our brain capacity can be used for thinking rather than storing facts?

Tomo Hawk That's a great idea. Can we also have a neural uplink-type affair we can plug in?

Ross Kobak Genetic manipulation will cater for everything from genetically engineered humans colonising other planets to more obscure fashion extremes such as genetic surgery. Natural selection will be dead.

Join in the discussion at www.twitter.com/sciencefocus and www.facebook.com/sciencefocus using #humanevolution

Oops!

• In the November issue we published the wrong puzzle solution on p128. The correct solution to question 8 on p135 of that issue can be seen at sciencefocus.com/winners

FOCUS

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News and views from the world of science



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Could carbon nanotubes be set to revolutionise microchip design?



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FEELING FOR FALSE FINGERS

New research to allow artificial hands to deliver a sense of touch.



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OLD BONES, NEW PROBLEMS

Why classifying this ancient skull is causing the experts a headache.

THE BIG STORY

MAKING MATTER FROM LIGHT

By making light behave as if it has mass, scientists have opened the door to the possibility of lightsabers

LIGHT COULD BE used to build three-dimensional structures, thanks to pioneering research that's produced a new form of matter. It involves light interacting with itself to behave as if it has mass and raises the prospect of creating *Star Wars*-style lightsabers.

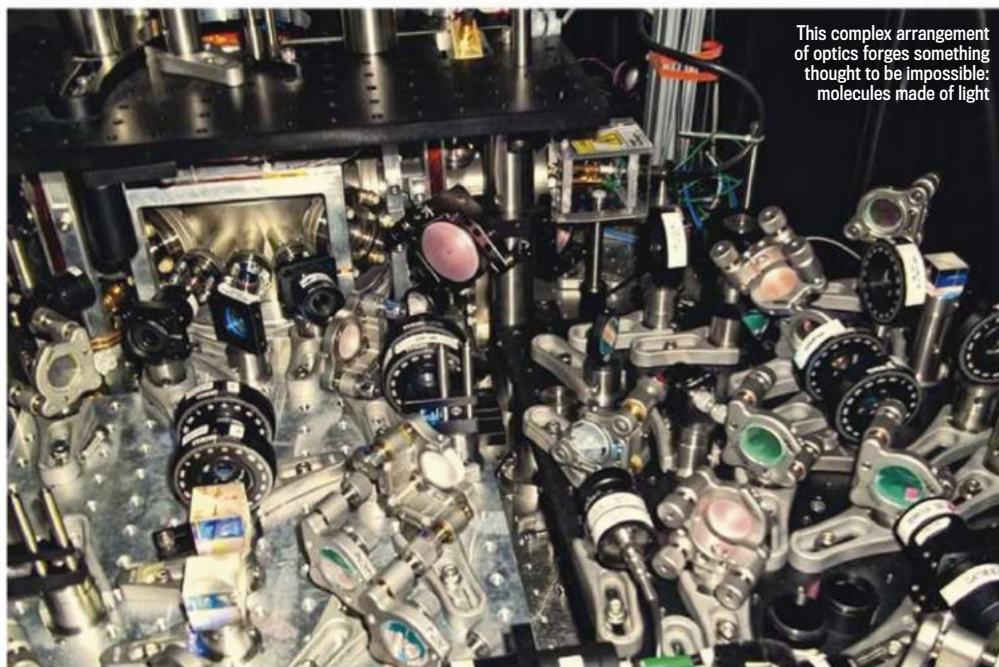
For decades, scientists had thought that light didn't interact with itself. Shine two laser beams directly at each other and they'll just continue as if the other isn't there. But researchers in the US have now managed to make light interact so strongly it binds together, a feat that was only believed to be possible in theory.

Light consists of tiny photons: elementary particles that have no mass and zip around at



Professor Mikhail Lukin of Harvard University surveys his light-matter machine

PHOTO: KRIS SNIBBE/HARVARD UNIVERSITY



This complex arrangement of optics forges something thought to be impossible: molecules made of light



299,792,458 meters per second. To bind them together, the team – led by Professor Mikhail Lukin from Harvard University and Professor Vladan Vuletic from Massachusetts Institute of Technology – used a laser to fire photons into a gas of rubidium atoms. This was cooled to just a few degrees above absolute zero.

When fired individually, each photon passed through the supercooled gas travelling at a much-reduced speed of around 1,000 meters per second before leaving again as a single photon. But when the researchers fired two photons into the gas, they found that the photons emerged from the cloud bound in pairs – creating, in effect, a molecule of light.

It's thought this pairing occurs because of the way the two photons move through the gas. The first photon enters the cloud and excites atoms in its way. But those atoms can't immediately be excited to the same degree again, so the second photon can't follow until the first has skipped further ahead. This results in the two photons travelling together. Indeed, the interaction between them is so strong that they begin to act like a 'photonic molecule'. "No one has ever seen this new state of matter in light before," says Vuletic.

One possible future application of the work is to use light, instead of electrical pulses, as the building blocks for a quantum computer using photons as the 'bits' of information. Such systems are inefficient today as light pulses have to be converted to an electrical signal for processing before being converted back. However, making photons interact could make all-optical computation possible.

"Until now photons have been seen as being a little boring, but we have now found a way to make them much more interesting," adds Vuletic. "It is amazing what level of control we now have for photons."

Vuletic adds that the next step for the team is to attempt to bind three or four photons together. They also have plans to make the photons repel, rather than strongly attract each other. This could allow scientists to build photons into a structure to create, for example, a crystal of light. "There are certainly a lot more avenues for research based on this work," says Vuletic.

And what of the possibility of creating *Star Wars* weaponry? "It's not an inapt analogy to compare this to lightsabers," Lukin said. "The physics of what's happening in these molecules is similar to what we see in the movies."

MICHAEL BANKS



TIMELINE

How our understanding of light developed

300 BC

Greek mathematician Euclid writes *Optica*, in which he describes the laws governing the reflection of light by postulating that light travels in a straight line.

1637

French philosopher René Descartes publishes a theory of light that is regarded as the start of modern optics. It assumes light has a wave-like behaviour.

1845

English scientist Michael Faraday shows that light is related to electromagnetism by demonstrating that magnetism can affect light in a 'dielectric' material.



1861

Scottish physicist James Clerk Maxwell unifies the theory of electromagnetism and optics, showing that light is one form of electromagnetic radiation.

1905

Albert Einstein postulates that light consists of localised particles – quanta. The theory suggests that light is massless and incapable of interacting with itself.

2013

Mikhail Lukin and colleagues show that photons can indeed interact with each other when travelling through a gas of ultra-cooled atoms.

ANALYSIS

Sougato Bose



Atomic physicist at UCL

“ I THINK THIS work is a milestone and a very exciting development. Although it doesn't fundamentally change our theories about light, the research does change how we view and think about the possibilities offered by such a fundamental constituent of nature.

Photons – small packets, or 'quanta', of light – certainly have many merits given that they are fast and don't lose energy as they travel through space. This has made them extremely useful for telecommunication via optical fibres, for example. But, there has always been a major drawback with their use in new technologies and applications, such as in quantum computers: they don't interact with each other. Interaction is important if we want to use light to carry out computation such as in logic gates.

Mikhail Lukin, Vladan Vuletic and their colleagues have now achieved this feat, accomplishing something that scientists have been trying to achieve for the last couple of decades. Many had previously tried to make photons interact through atoms held in optical cavities – an arrangement of mirrors that traps light inside. What the new work shows is that so much is possible without boxing the photons up in cavities.

Yet this is, for now, just a proof of principle. A lot more work still needs to be done before it can become more reliable to be practically useful. **”**



WHAT DO YOU THINK?

What are the chances of weaponising solid light to create lightsabers? Let us know your thoughts at [facebook.com/sciencefocus](https://www.facebook.com/sciencefocus)

STORM

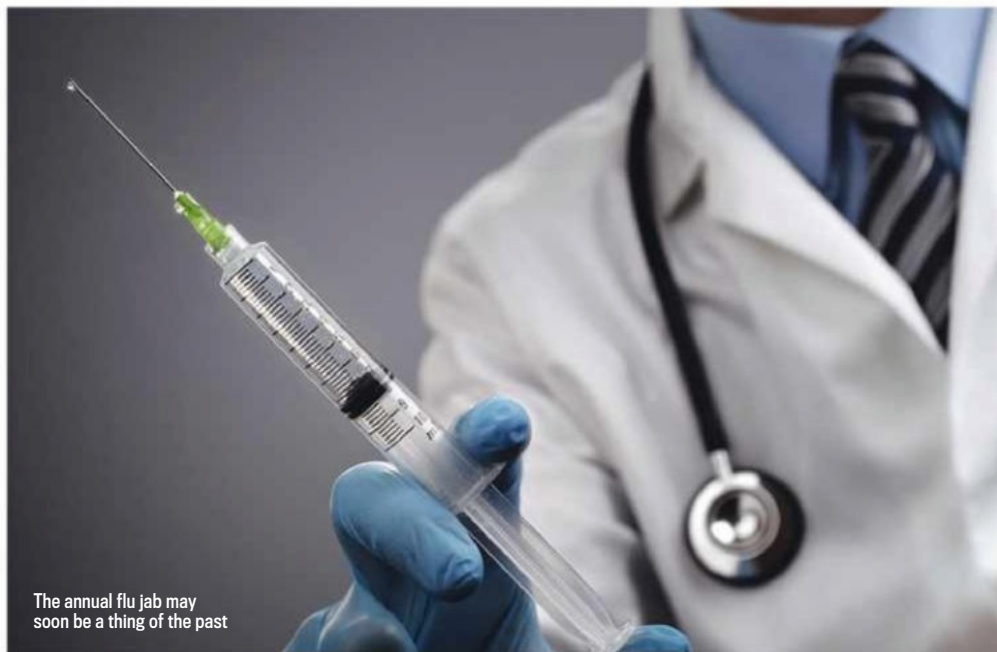
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The annual flu jab may soon be a thing of the past

Virology

One flu jab to rule them all

HUMANITY'S GREATEST foe, the flu virus, could be about to bite the dust. It's so far been impossible to create one vaccine to protect against all types of flu. This is because the virus is constantly evolving, but the key ingredients for a universal vaccine have now been identified.

By studying the victims of the 2009 H1N1 swine flu pandemic, researchers from Imperial College London, led by Ajit Lalani, have discovered what makes some people vulnerable to the infection. "We had to work super-fast, because the whole experiment was based on the fact that the population was vulnerable to the new strain," said Lalani.

The team looked at immune systems to work out why some people got sick while others barely suffered a sneeze. It turned out that those who escaped full-blown flu

were protected because they had higher numbers of a certain type of T cell. These T cells were able to recognise the new strain of flu – even though it looked very different from previous strains – because they targeted core parts of the virus that hardly ever change. The antibodies produced by conventional vaccines don't recognise these core parts.

Among these T cells, explains Lalani, those with a certain 'killer' personality are the ones that will stop you getting ill. "They travel rapidly to the sites of infection – your nose, throat and the upper airways of the lung – and kill the virus," he says. Now the scientists hope to make a new kind of vaccine based on the protection offered by killer T cells – one that will allow the virus to spread, but stop it making us sick.

HAYLEY BIRCH

1 MINUTE EXPERT The A14

As in the road? Have I picked up *Top Gear* by mistake?

Yes, as in the road – but the A14's not just any old lane or highway. It's about to become the UK's first 'smart road'.

What's so smart about it?

A 112km (70-mile) stretch from Felixstowe to Cambridge is to be equipped with sensors that gather and transmit data on traffic movement. As well as helping the traffic control officers do their job, this data could be used to send alerts to your mobile phone to warn of diversions, congestion, accidents or speed limit changes. In future, the system could also control the speed of suitably equipped vehicles.

How does it work?

The system, developed by BT, the Department of Transport and Cambridge firm Neul, transmits data in the 'white space' between television channels in the radio frequency (RF) spectrum. This is just one of a number of white space projects being trialled in 2014.

Why is white space important?

Because with today's myriad connected devices, we're running out of spectrum. As the 'internet of things' starts to grow, we're going to have to find ways to use the RF spectrum more efficiently.

WHO'S IN THE NEWS?

Peter Higgs

The theoretical physicist went AWOL after winning a Nobel

What did he say?

At first nothing. The day he and Belgian François Englert jointly won the 2013 Nobel Prize for Physics, the 84-year-old physicist was on holiday without a phone. He did, however, issue a statement later via Edinburgh University, saying "I am overwhelmed to receive this award."

What was the prize for?

His solution to the mystery of why particles have mass. He suggested they interact with an energy field that would reveal its existence through the existence of Higgs particles.

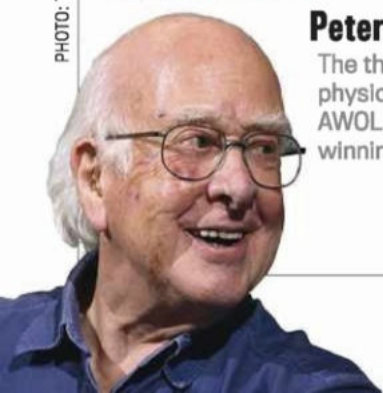
Why was the prize shared?

Because Peter Higgs wasn't the only one to conclude that this field must exist. Englert

and his late partner Robert Brout published a similar theory in the same year as Higgs. So too did Gerald Guralnik and Dick Hagen in the USA a little later.

What does he win?

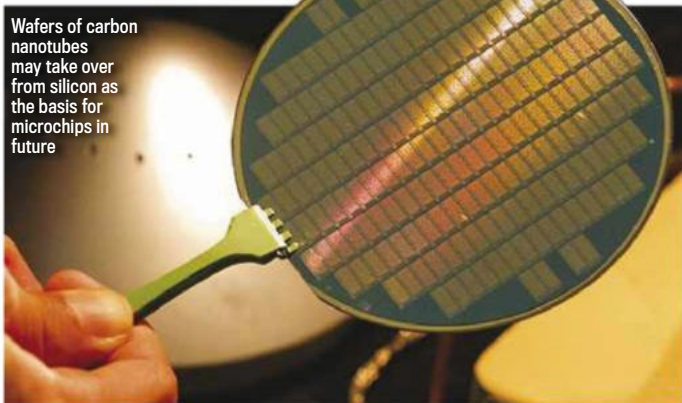
The prize is 8 million Swedish Krona (£776,000), which Higgs and Englert will share, and scientific immortality.



Microelectronics

Computing enters the carbon age

Wafers of carbon nanotubes may take over from silicon as the basis for microchips in future



CEDRIC: THAT'S THE name of the world's first computer made from carbon nanotubes. Created by scientists in the US, the computer could usher in a new, post-silicon era of faster, more efficient devices.

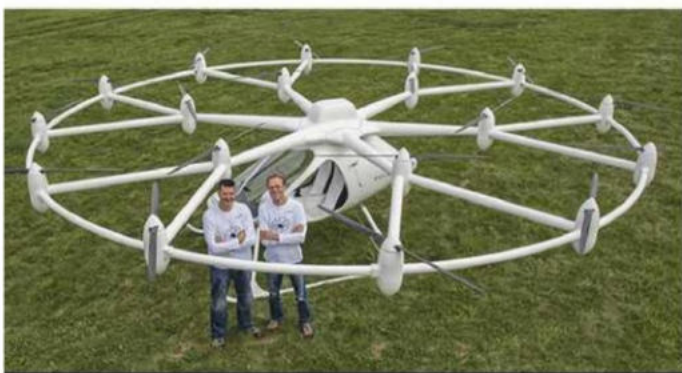
If gadgets are to carry on getting smaller and faster, silicon transistors have to become tinier so that more of them can be fitted onto a chip. The downside is that smaller transistors tend to waste power and generate more heat. Carbon nanotubes (CNTs) – rolled-up sheets of carbon as little as one atom thick – have been mooted as a possible successor to silicon. “These require less energy than silicon to switch on and off,” says

Professor Subhasish Mitra at Stanford University, “so they generate less heat and can be packed into smaller devices.”

The result is a fully functioning computer, albeit a very basic one. It operates on one bit of information, and can only count to 32. But, crucially, the only limit is the system's memory – scale it up and it'll be able to carry out any computational task.

“We're not saying that carbon is going to replace silicon overnight,” says Mitra, “but with this computer, we're on our way to building devices that are 10 times more powerful than their silicon counterparts.”

JAMES LLOYD



MEN AND ROTORS

Meet the e-volo Volocopter VC200, described by its German makers as ‘a new category in aviation’. Electrically powered, the two-person Volocopter uses 18 separate rotors, steering and banking by changing their relative speeds. It's expected to make its maiden flight very soon.



PATENTLY OBVIOUS

with James Lloyd
Inventions and discoveries that will change the world



Hand-controlled hatchbacks

WHEN YOU'RE DRIVING, gestures are usually reserved for that idiot who's just cut you up on the motorway. Google, though, is looking to put them to better use with a car that's controlled by your hand movements.

Google's proposed system uses a ceiling-mounted, three-dimensional camera to monitor the movement and position of your hands. Swipe up towards the air-conditioning vent and you'll raise the temperature; tap your ear and you'll be able to turn off the radio. Similar gestures will allow you to control your car's windows, windscreen wipers, sunroof and even your seat position. Presumably you'll have to be careful not to wave at passers-by.

With Google also currently developing a self-driving car, it looks like motoring in the future could be as easy as sitting back in your chair, and waving your hands like you just don't care.

Patent number: US 20130261871

Book signings go digital

BOOK SIGNINGS ARE a great way to meet authors, but how do you get an eBook signed? Apple has an answer: it's patenting a system that embeds autographs into eBooks. When the reader's tablet is near to the author's during a signing, an ‘autograph page’ is generated in the reader's eBook. This page has a blank area to accept the author's signature, a personalised message and a photo to prove that you really did meet your literary hero.

Patent number: US 20130254284

The smart cash register

WE'VE ALL RECEIVED too much – or too little – change from an absent-minded shopkeeper at some point. That's why Reading-based Safia Technology has invented a cash register that can detect mistakes. The cash tray monitors the weights of the coins and notes. After each transaction, a built-in computer calculates whether the new weights tally with how much change should have been returned to the customer. If they don't, the till flashes up an alert.

Patent number: GB 2500587

Space exploration

Water found on Mars



NASA'S MARS ROVER Curiosity has made the surprising discovery that water is plentiful in the Red Planet's surface soil. Instruments showed that it makes up about two per cent of dirt sampled at a spot dubbed Rocknest in Gale Crater.

Though its molecules are bound up with other chemistry, water vapour is readily released when the soil is heated to around 835°C. This means there will be a handy and accessible supply for drinking, cooking, washing and making fuel when human missions finally arrive.

Dr Laurie Leshin, Dean of the School of Science at Rensselaer Polytechnic Institute, New York, led the discovery team. She told *BBC Focus*: "The water is bound in the dirt right at the surface

and it is fairly easy to get out. We expect to find it just about anywhere. So if you're a human explorer going to Mars, this is really good news."

Along with sulphur dioxide and carbon dioxide, the rover also detected oxygen and some chlorine in the soil – which is less good news. It suggests the presence of perchlorate, a mineral that is dangerous to astronauts and was also found by NASA's Phoenix lander in the high arctic.

Meanwhile in another Mars Science Lab experiment, Curiosity has failed to sniff out any methane in Mars's atmosphere. This will dampen the hopes of scientists looking for evidence of current microbial life, but shows that we still have much to learn about the Red Planet.

PAUL SUTHERLAND

Neuroscience

NEW BRAIN WAVES DISCOVERED

A FLATLINE SIGNAL in a coma patient's brain scan is considered the lowest possible state of brain activity, and a potential sign of brain death. But one unusual case has led scientists to suggest there is a deeper state associated with previously unknown patterns of brain activity.

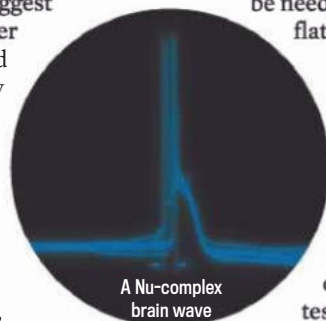
Unfamiliar, spiky-looking brain waves, now called Nu-complexes, were first spotted in a coma patient receiving anti-epileptic drugs for convulsions. Puzzled, the doctor monitoring his brain activity phoned Professor Florin Amzica at the University of Montreal. "He had no idea what was going on in that patient," says Amzica. "Our initial guess was that it was a

very deep state of coma, so we decided to see if we could reproduce that in animals." His team induced a similar state in cats by giving them a higher dose of anaesthetic than would be needed to produce a flatline response.

There is no suggestion that very deep coma patients are being misdiagnosed as brain dead, as flatlining is only one of a number of tests for brain death

that doctors apply. The discovery of Nu-complexes could, however, have therapeutic benefits. Giving a stronger dose of anaesthetic could reveal underlying brain activity. Amzica also thinks inducing the deeper coma state could help protect a patient's brain from damage.

HAYLEY BIRCH



CD sewage treatment: clean water is just a tune or two away



THEY DID WHAT?!

Scientists dunk CDs in sewage

A team of researchers led by Prof Din Ping Tsai, a physicist at the National Taiwan University, have been immersing CDs and

CD players in raw sewage, then hitting play.

Why did they do this?

The researchers were looking at a new method of waste treatment, which involves a spinning CD coated in tiny rods of zinc oxide. Under UV light, the rods act as a photocatalyst, breaking up molecules of organic pollutants. The team used discarded CDs as

they are plentiful and cheap and environmentally friendly.

So what happened?

A treatment unit comprising CD drive, UV light and pump removed 95 per cent of pollutants from waste water in an hour. It's hoped the technology can be scaled up, as it's quicker and less energy-intensive than existing water treatment techniques.



WHAT THE PAPERS SAY

Henry Gee on the latest from leading journals

BEEES THINK BIG IN THEIR TINY MINDS

ABSTRACT THOUGHT IS an ability that we humans jealously guard as something that only we can achieve, thanks to our enormous brains. It'll be a surprise to many, therefore, that it's something that honey bees are also capable of, even though their brains are the size of a pinhead.

Writing in *Proceedings Of The Royal Society B*, Aurore Avarguès-Weber and Martin Giurfa of the Research Center for Animal Cognition in Toulouse, France, review the evidence that the brains of bees are capable of what they call 'conceptual learning'. In other words, extracting and generalising features of their environment and applying them in different situations.

Concepts are the cornerstones of human cognition. Where would we be if we couldn't learn relationships such as 'same', 'different', 'larger than' and 'better than', and apply

these ideas independently of the physical nature of the objects linked by such relationships? 'More than', for instance, can be applied to two piles of potatoes as well as to two piles of coins.

Yet there's a wealth of evidence that bees can tell the difference between concepts such as left and right, or same and different. There are even experiments, involving training bees to associate colours and patterns with a sugary reward, that show they can tell the difference between two different concepts simultaneously.

In humans, concepts are associated with a part of the brain called the prefrontal cortex. In bees and other insects, the thinking is done in structures called mushroom bodies. Fruit flies, with less complex mushroom bodies than bees, do not appear to be able to think conceptually.



The humble honey bee is cleverer than you think

It could be important that honey bees are social. They live in complex environments in which they communicate information, such as the location of flowers. So it makes sense that they are able to understand concepts. In the same way, it could be that the size of the human brain is connected with our highly social lives, compared with the less social lives of other apes.

Deep thoughts seem to be more linked with the way we live, rather than our perceived status on the evolutionary tree. And that makes as much sense for bees as for people.



HENRY GEE is a palaeontologist and evolutionary biologist, and a senior editor of the journal *Nature*

Environmental science

OCEANS IN POOR HEALTH

THE STATE of the oceans is worse than was previously thought. The International Programme on the State of the Ocean (IPSO), a non-governmental group of marine scientists, has declared that 'risks to the ocean and the ecosystems it supports have been significantly underestimated'. The report states that mass

extinctions among marine species are increasingly likely unless action is taken to combat the triple threat of warming, increased acidification due to CO₂ absorption, and decreasing levels of oxygen.

The latter is blamed on pollution by sewage and fertiliser run-off, which causes algae to bloom. Coral,



which plays a key role in the oceanic food chain on which many human lives ultimately depend, is said to be particularly at risk from warming and acidification.

Over-fishing was also highlighted as a concern in the report, which calls for tighter controls on CO₂ emissions and improved fisheries management.

A manta ray cruises over a reef; marine scientists say urgent action is needed to protect underwater habitats

Neuroscience

Sleep helps your brain clean up



By-products of brain activity build up in the spaces between brain cells before being flushed out while you sleep

RESearchers at the University of Rochester Medical Center in New York believe they've figured out why sleep clears the mind so well, a question that has long puzzled scientists.

The brain is our most metabolically active organ but it's not connected to the body's normal waste removal network. Last year Maiken Nedergaard showed that the brain has its own cleaning system, and now she and her colleagues have discovered that this system is much more active while we sleep.

Active, wakeful brains accumulate metabolic waste in the spaces between cells. The team measured the volume of this space

and found that it expands in the brains of sleeping mice, allowing more fluid to flow through and clear out the waste.

"The brain only has limited energy and it appears that it must choose between two different functional states – awake and aware, or asleep and cleaning up," said Nedergaard. "You can think of it like having a party. You can either entertain the guests or clean up, but you can't really do both at the same time."

Since some of these waste products also build up in the brains of patients with neurodegenerative diseases, this research may also point the way to improved treatment.

SEDEER EL-SHOWK

Nuclear physics

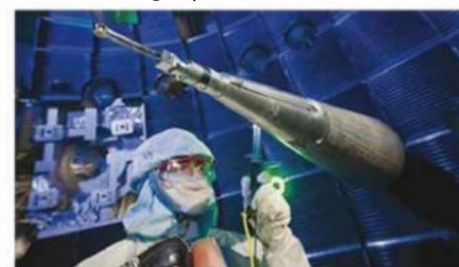
Fusion power edges closer

AN IMPORTANT BREAK-even point in the effort to harness nuclear fusion has been reached, say US scientists. Fusion is a power source that could provide an unlimited supply of energy. The breakthrough occurred on 28 September at the National Ignition Facility (NIF) in California, where scientists focus powerful lasers on a small pellet of hydrogen in an effort to trigger fusion. For the first time, an experiment released more energy than was absorbed by the fuel.

The idea is that the hydrogen nuclei will fuse into helium nuclei and ignite a self-sustaining reaction – the same process that powers the Sun. The news was revealed in an internal email sent by Dr Ed Moses, director of the NIF. Experts stress that the experiment is still far from achieving the energies needed to reach the goal of 'ignition' – the point when the reaction becomes self-sustaining. Nevertheless, it's being recognised as a significant step on the road to a goal that has eluded science's best efforts for a long time.

JAMES LLOYD

Tests carried out at the National Ignition Facility are working towards harnessing the power of nuclear fusion



Cybernetics

PROSTHETIC LIMBS TO GET TOUCHY-FEELY

THE NEXT ADVANCE for prosthetic limbs will be to hook them up to the brain to provide a sense of touch. And now scientists are a step closer to giving real-time sensory feedback via linked neural implants.

A team led by Sliman Bensmaia, an assistant professor of biology at the University of Chicago, identified the pattern of neural

activity in the brains of macaque monkeys that occurs when their hands are touched. When this neural activity was then artificially generated, the monkeys responded as if their hands were actually feeling something. The research paves the way for sensors on a prosthesis to provide a 'real' sensation of touch.

RUSSELL DEEKS



We could soon have artificial limbs that enable us to get all touchy-feely

Palaeoanthropology

SKULL TELLS A SURPRISING STORY

Skull 5, one of five discovered in 2005, suggests there may have been fewer species of early man than was thought. Inset: how the skull's owner might have looked

THE SCIENTIST WHO discovered five ancient skulls says they could challenge many of our current assumptions about early humans. In 2005, palaeoanthropologist David Lordkipandize unearthed five skulls in Dmanisi, Georgia. The quintet all date from approximately 1.8 million years ago, but they display varied characteristics.

One in particular, Skull 5 (seen above), had tentatively been given the new classification *Homo erectus ergaster georgicus*, as it shares qualities with two known species: *Homo*

erectus and *Homo habilis*. Now, in a paper published in the journal *Science*, Lordkipandize argues that the five skulls exhibit no more variation than you'd expect to see in five modern humans picked at random. He suggests they're more likely to be *Homo erectus* skulls of people of different ages and sexes.

Prof Christoph Zollikofer of the University of Zurich's Anthropological Institute and Museum, who co-authored the report, said the five "look quite different from one another, so it's tempting to view them as different

species. Yet we know they came from the same location and the same geological time, so they could represent a single population of a single species."

The Dmanisi findings suggest it's possible that many existing theories about early humans could be wrong. These theories propose an array of *Homo* species including *H. erectus*, *H. habilis*, *H. rudolfensis* and others, based on the discovery of differently shaped skulls from different time periods in different places.

RUSSELL DEEKS

NEWS IN BRIEF

Snakes on Mars

• A snake-like robot is currently being designed to assist NASA's Curiosity rover. Presently, many areas of Mars's surface are inaccessible to Curiosity because of the rover's large size. SINTEF, a Scandinavian research organisation, believes a detachable snake arm powered by the rover would improve manoeuvrability and also allow samples of soil to be collected and returned to Earth by future missions.

Biobots to the rescue

• Emergency rescue services could soon have a new weapon in their life-saving arsenal: remote-control cockroaches. Software developed at North Carolina State University can track the movements of these 'biobots' as they alternate between unrestricted movement and following a series of commands, and use the data to map out an area such as the inside of a collapsed building.

Legless lizards

• Four new species of reptile have been discovered by biologists in California. Adapted to living in loose, moist soil in sparsely inhabited areas, the legless lizards can be distinguished by the colour of their stomachs, the number of their vertebrae, and the number and arrangement of their scales. It's thought that legless lizards lost their limbs to be able to burrow more quickly, wriggling like snakes to avoid predators.



One of the new species of legless lizard discovered: *Anniella grinnelli*

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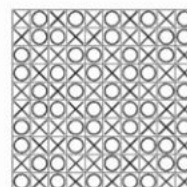


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MINDGAMES PUZZLE
No cheating! Don't look at
this until you've attempted
the puzzle on p143.



INSIDE SCIENCE

ROBERT MATTHEWS

Christmas is coming and the columnist is getting fat; or is he...

SOME PEOPLE PREPARE for Christmas well in advance, getting their cards posted, presents ordered and booze in some time in early September. I am not one of those people. I leave everything far too late – with one exception. Around 1 December, I go on a diet. The idea is that by dropping half a stone in three weeks, I can push food and drink into my face for a few days without worrying. Well, that's the theory. In practice, I usually only execute half of it – and no prizes for guessing which half.

My whole attitude towards dieting has been on a rollercoaster this year, just like my weight. The reason is a flurry of confusing messages about whether I should be worrying at all. Earlier this year, a team led by Katherine Flegal of the US National Center for Health Statistics, Maryland, published a study suggesting that being overweight isn't so bad for us after all. By overweight, they mean people whose Body Mass Index (BMI) – found by dividing their weight in kilograms by the square of their height in metres – is between 25 and 30. Sure, it's still bad to be obese (that is, have a BMI over 30), but according to the research, we chubby types actually have a mortality rate six per cent lower than those in the supposedly 'healthy' BMI range of around 19 and 25.

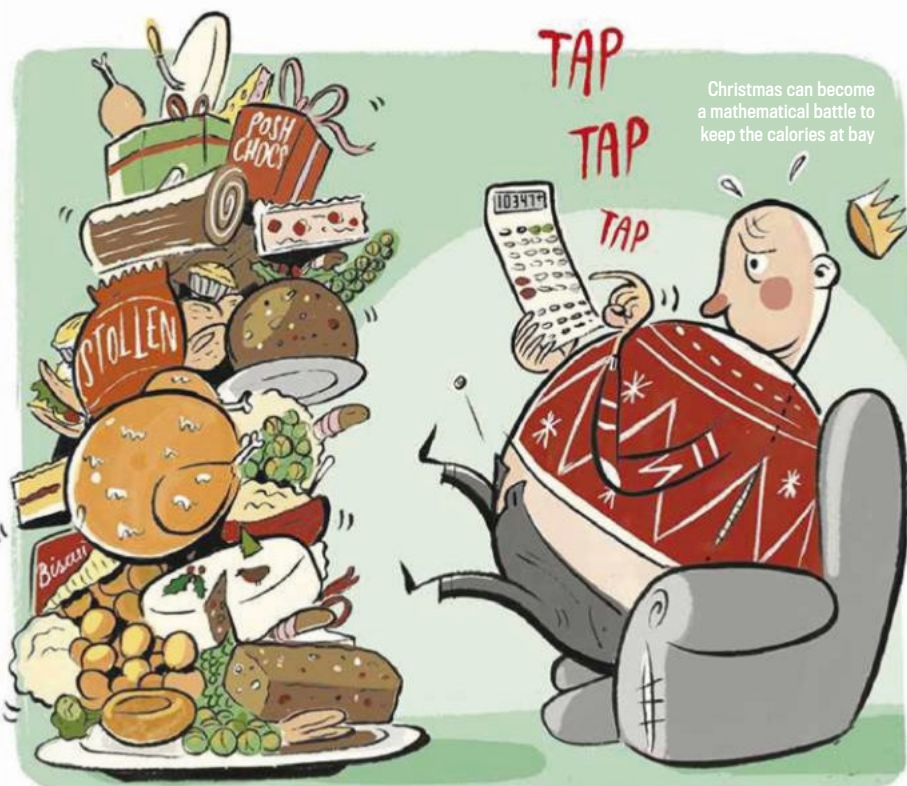
Reading this put me – with my BMI of 26 – in a good mood for at least an hour... until I started reading

around the subject. Amazingly, while doctors, nutritionists and even the World Health Organisation seems happy for you and me to use the BMI to gauge our healthy weight, many experts on obesity have doubted its reliability for years.

And it's not hard to see why: just try working out the BMI of a professional rugby player or boxer, like the current world heavyweight boxing champion Wladimir Klitschko. He's 6ft 6in (1.98m) and weighs in at 17st 5lb (110kg). Plug those figures into the BMI formula, and you'll get a figure of over 28 – well into lard-arse territory. Yet one look at him shows this is baloney: he's got no spare fat, but a heck of a lot of high-density muscle – a distinction the BMI doesn't make.

Clearly, as a measure of healthy weight, BMI is missing something big. Suspicion is falling on its failure to distinguish between two types

“As a measure of healthy weight, body mass index is missing something. Suspicion is falling on its failure to distinguish between types of fat”



of fat: the 'belly fat' we can all see, and the invisible 'visceral fat' wrapped around our organs, which has been linked to diabetes and cardiovascular disease.

So if BMI doesn't capture this, what does? Being a maths geek, I do like formulas, and I was delighted to discover there's a new, turbo-charged version of BMI based on a study of data from over 14,000 people by Drs Nir and Jesse Krakauer of City College of New York. Known as A Body Shape Index (ABSI), it takes into account not just height and weight, but also where body-fat is distributed, via a waist circumference measurement round the top of the hips. Statistical curve-fitting led the Drs Krakauer to the following formula for the ABSI: divide the fifth power of your height in metres by the fourth power of your weight in kilograms, take the sixth root of the result and multiply that by your waist circumference in metres. Roughly speaking, a healthy ABSI is below around 0.08 – a bit more for men and a bit less for women.

I have to admit that while I like formulas, I quickly went off this one. Plugging my stats turned my 'healthy' BMI of 26 into a distinctly dodgy ABSI above 0.08. Still, with his waist measurement of 34in (86cm), at least Wladimir will be happy: he's swapped his pudgy BMI of 28 for a healthy ABSI of 0.066.

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

So it's back to the pre-Christmas diet for me. Or maybe I should ask Santa for an elasticated tape-measure? ■

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HELEN CZERSKI

The sight and sound of a lightning strike is a journey into the atmosphere

THERE ARE FEW things I love more than a thunderstorm. I love the feeling of being completely surrounded by a cacophony of sound, and the reminder that the atmosphere is a vast three-dimensional structure that's anything but passive. The atmosphere is thin relative to the size of the Earth. From outer space, it looks as though we are crawling about on the bottom of a shallow puddle of air. But this puddle is vast compared with a human being, and so are the thunderstorms that sometimes happen in it.

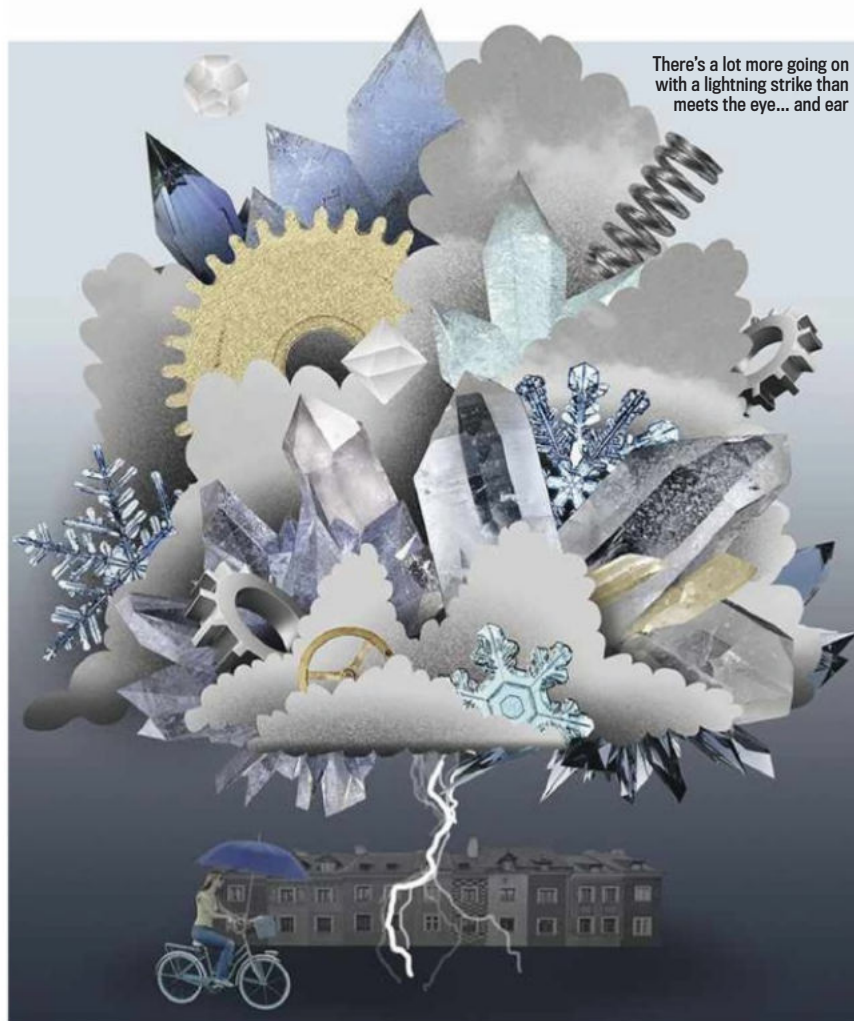
As I found out recently, this perspective offers limited consolation when pedalling home in a storm, but the sound of thunder has a lot to offer the sodden cyclist. It's immersive, in a few too many ways for comfort. What I really like about the sound is that it's letting us hear the structure of the atmosphere. Just for a moment, that invisible mass of silent stuff surrounding us shows some of its true character.

It started with a bolt of lightning: a temporary tube of broken air. On the ground, all that concerned me was trying to keep the rain out of my eyes. But high above my head, tiny ice crystals were being pummelled inside the thundercloud, causing an electric charge to build up. As I cycled down the hill, some of this charge found its way to the ground just by the football stadium. A thin line of air molecules broke into charged fragments, changing this thread of air from being a safe insulating barrier into an electricity superhighway. For about 20 milliseconds, thousands of amps of current rushed down to Earth. For comparison, the plugs in your house can only cope with 13 amps of current.

Cycling towards that lightning strike was a bit like time travel, because I got to experience the lightning bolt twice. First I saw the light, given out as the rush of electricity heated the air near it. It took only the tiniest fraction of a second to reach me, but it showed me where the atmosphere had broken. As soon as you see light, you know that there is also sound rushing towards you along your line of sight, and it just hasn't reached you yet. I kept cycling, watching the air and seeing nothing, but knowing that a huge noise was rippling towards me.

This rapid expansion of air in the conducting tube hits the atmosphere around it like a hammer. Sound travels slowly compared to light, at only 340 metres per second in air. And here's the best part. The first bit of thunder you hear is the sound of the lightning at the ground, because the distance from you to the place the lightning hits is shortest.

“High above my head, tiny ice crystals were being pummelled inside the thundercloud, causing an electric charge to build up”



There's a lot more going on with a lightning strike than meets the eye... and ear

Sound from a bit higher up the lightning bolt reaches you later because it had further to travel. As the thunder rolls on, you are listening to the whole lightning bolt from the bottom to the top. So several seconds after the strike, I got to experience the whole thing again, in sound instead of light.

The crack at the start is the true sound of the shock caused by the lightning. It's got a mixture of different pitched sounds in it, like someone hitting all the keys on the piano at once. As the thunder rolls on it sounds deeper, because the high-pitched sounds are absorbed by the air. The further the sound travels to reach you, the more of that atmospheric filter it has passed through.

I arrived home drenched but happy. Inside is the best and safest place to be when there's a storm going on, but just sometimes I want to be outside, properly immersed in it all. I went inside and wrung most of a cloud out of my clothes. ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter who appears regularly on *Dara O Briain's Science Club*

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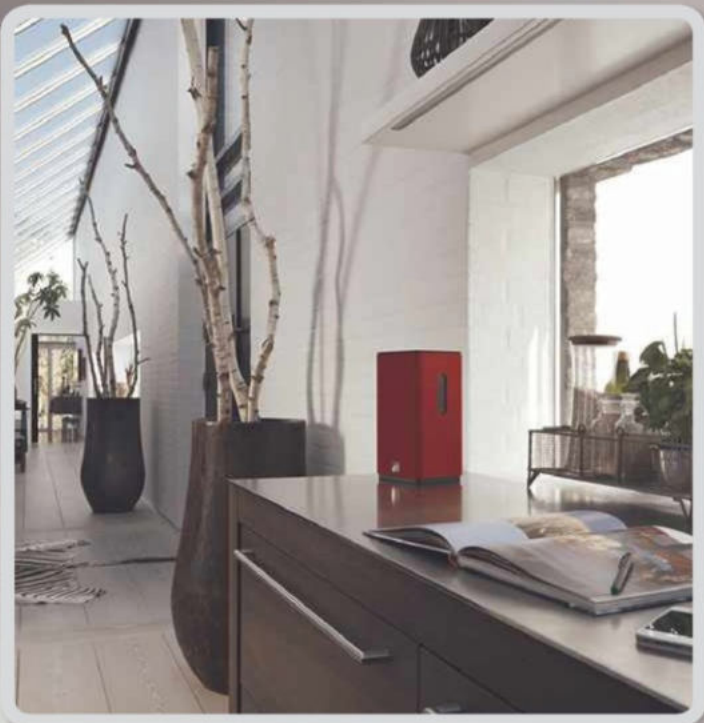
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THE TRUTH ABOUT CAFFEINE

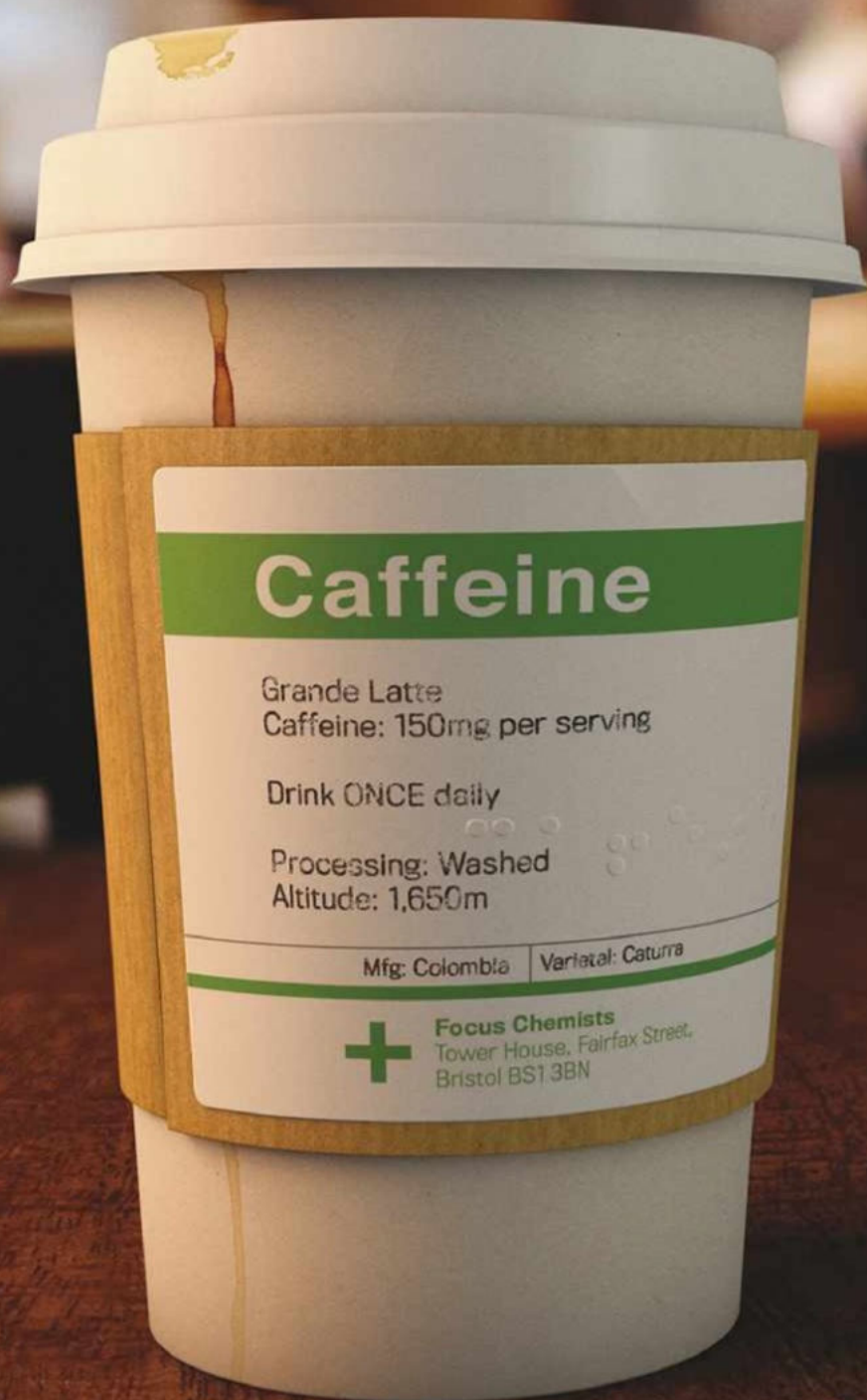
It's the world's most widely consumed drug, but how much do we really know about caffeine's effects? **Emma Davies** asks if there's trouble brewing

ADDITIONAL REPORTING: NATALIE KEIR

MOST OF US reach sleepily for a morning cup of tea or coffee to set us up for the day. Yet research suggests that a hit of caffeine does little more than reverse the effects of withdrawal after a night's abstinence, in much the same way that heroin addicts eventually take the drug simply to avoid the horrors of going cold turkey. Recently, new research has looked at the effects of caffeine and is questioning whether it's more dangerous than we think.

"What is clear is that habitual use – even one cup of tea per day – leads to withdrawal after a period of abstinence. A well-known side-effect of withdrawal is sleepiness, which can be reversed by ingestion of the drug," says Michael Keane from Dublin City University.

ILLUSTRATOR: MAGICTORCH



➔ The shape of the caffeine molecule is similar to that of adenosine, which suppresses activity in the central nervous system. Adenosine receptors are found throughout the body, and when adenosine binds to them it inhibits the release by neurones of several neural transmitters, produces sedation and has anti-convulsant activity. Caffeine is an adenosine antagonist, which means that it binds to the receptors but without reducing neural activity.

Caffeine's effects are difficult to study because different people have varying levels of tolerance. If you regularly consume medium to high levels you'll become far less sensitive to it. Although caffeine may help to keep us awake and gives small improvements in physical performance, it causes jitteriness and anxiety in some people and raises blood pressure by causing blood vessels to narrow. During withdrawal, the blood vessels widen again, which increases blood flow to the brain and causes headaches. In the absence of caffeine, withdrawal effects lessen within a few days, and disappear after about a week.

When a team of psychologists from the University of Bristol set caffeine users

and non-users a range of tasks to measure the effects of overnight caffeine abstinence, they discovered that by 10.30am, those used to a morning dose of caffeine were starting to suffer mildly from withdrawal. By the afternoon, effects became



Peter Rogers of Bristol University is studying whether caffeine really is a performance-enhancing drug

more severe, with sleepiness, lower mental alertness and poorer performance on reaction and memory tasks.

Caffeine improved reaction times but did not improve mental performance. Although caffeine makes medium-high consumers 'faster', they are not 'smarter', argues the Bristol team. Tolerance to caffeine's effects on sleepiness means that "frequent consumption fails to enhance mental alertness and mental performance," suggest the researchers.

Strangely, caffeine had little effect on non-consumers, apart from making them feel less sleepy. "I puzzled for a long time why caffeine wasn't increasing alertness in non-consumers – it seemed odd," recalls lead researcher Prof Peter Rogers. The key lay in separating alertness – the ability to focus mentally on a task – from wakefulness, which hadn't really been done before. Rogers worked out that caffeine wasn't improving alertness in non- and low-consumers because any positive effects were being cancelled out by jitteriness and anxiety.

Rogers largely gave up caffeine several years ago, though he occasionally drinks coffee to keep him awake on long car

"I puzzled for a long time why caffeine wasn't increasing alertness in non-consumers - it seemed odd"

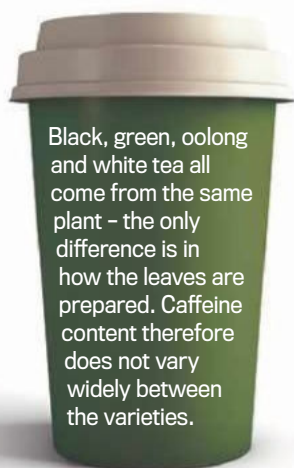
Peter Rogers, Professor of Biological Psychology, University of Bristol

journeys. "Every time I go through withdrawal again," he says, "it still takes me slightly by surprise."

A DANGEROUS HABIT?

Too much caffeine can speed up the heart, or cause abnormal heart rhythms. Very large amounts can be toxic and extreme overdose can cause death. An average adult would need to drink about 100 cups of coffee in a day for this to happen, but even smaller amounts can have negative effects. A study of almost 45,000 people between 1979 and 1998 by the University of Queensland, Australia, suggests that men who drank 28 cups of coffee per week were 56 per cent more likely to die from all causes before the age of 55, while women more than doubled their risk of mortality. Lead researcher Carl Lavie acknowledges that more research is needed, but in the meantime advises moderation.

The US Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) are both investigating the safety of caffeine. The FDA is acting in response to the addition of caffeine to an increasing number of products,



Black, green, oolong and white tea all come from the same plant – the only difference is in how the leaves are prepared. Caffeine content therefore does not vary widely between the varieties.

CAFFEINE COUNTER

How the caffeine content of some popular drinks and snacks stacks up



Can of 7 Up/Sprite
0mg



28g bar of milk
chocolate **6mg**



28g bar of dark
chocolate **20mg**



100ml Häagen-Dazs
coffee ice cream **29mg**



Can of cola
30-45mg



Can of iced tea
30-60mg



Cup of green tea
30-60mg



Caffeine hangs around in the body far longer in pregnant women, so cutting back is recommended

while EFSA was asked by the European Commission to give advice on the risk of adverse health effects as a result of caffeine intake 'from all sources'. Although caffeine is found in a wide range of products, including chocolate, the greatest concerns surround energy drinks, the fastest-growing sector of the UK drinks market since 2004, according to a report for the UK Food Standards Agency by its Committee on Toxicity (COT). A typical energy drink contains about 80 milligrams (mg) of caffeine per 250ml can. This compares with 60-80mg of caffeine in an average (237ml) cup of instant coffee and up to 135mg per cup of filter coffee. A can of cola contains 30-45mg of caffeine.

Caffeine has a half-life in the body of about five hours, but can hang around for up to 30 hours in certain cases, including in women taking oral contraceptives, pregnant women and young children. These groups are more susceptible to



NOW HERE'S THE GOOD NEWS

While some studies have pointed to the negative effects of caffeine consumption, others highlight the benefits

WORDS: NATALIE KEIR

1 Researchers at Sweden's Institute of Environmental Medicine found that drinking coffee daily could **reduce a man's risk of prostate cancer**. The May 2013 study found that for each cup of coffee drunk per day, there was a 3 per cent reduction in the risk of developing slow-growing prostate cancer. There was a lower reduction of 2 per cent in aggressive cases.

2 Drinking coffee could **reduce the risk of developing type 2 diabetes**, a 2010 paper published in the *Journal of Agricultural And Food Chemistry* suggests. Tests found that in mice, coffee consumption prevented high blood sugar levels and improved insulin sensitivity, thereby reducing the risk of diabetes.

3 Drinking three cups of coffee a day could significantly **reduce the risk of developing Alzheimer's disease**, a 2012 study suggests. Researchers at the University of South Florida monitored 124 volunteers for four years, looking for signs of mild cognitive impairment. Those who developed such impairment were found to have 51 per cent lower caffeine levels at the beginning of the study than volunteers who remained cognitively healthy.

4 Increased caffeine intake could **benefit those who suffer from non-alcoholic fatty liver disease**



(NAFLD), a study published in April 2013 revealed. Scientists at Duke University School of Medicine found that caffeine stimulated the metabolism of lipids stored in liver cells, and reduced the fatty liver of mice who were on a high-fat diet. The findings suggest that drinking four cups of coffee a day could prevent the progression of NAFLD in humans.

5 A 2012 study by researchers from the American Cancer Society found that drinking four cups of coffee daily could **cut mouth cancer risk in half**. The reduced risk may not actually be due to the presence of caffeine in the drink, but rather to the naturally occurring antioxidants in coffee. Smokers and drinkers exhibited the same risk reduction as anyone else.



Cup of tea
40-60mg



Voltz 5-Hour Energy
Shot **50mg**



Pro Plus tablet
50mg



Cup of instant
coffee **60-80mg**



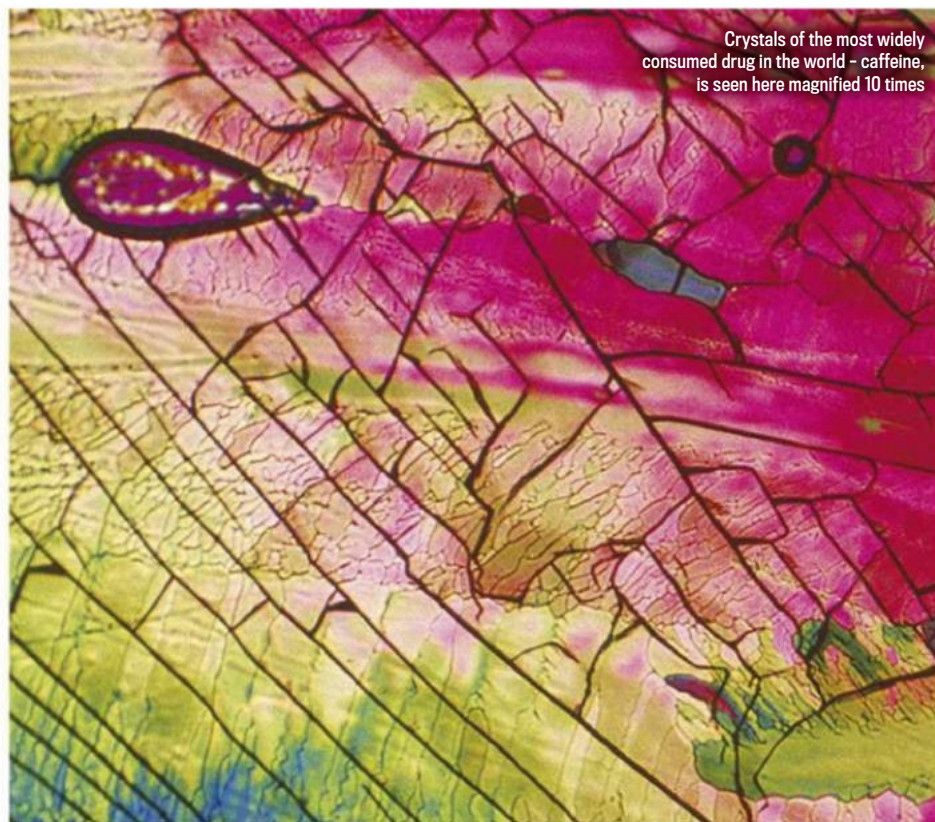
Can of Red Bull
80mg



Cup of filter
coffee **80-135mg**



Starbucks Grande
Latte **150mg**



Crystals of the most widely consumed drug in the world – caffeine, is seen here magnified 10 times

“People’s consumption of drugs, including caffeine, has a genetic basis”

Professor Marcus Munafo, a University of Bristol psychologist

Glasgow’s Alan Crozier has analysed espresso coffees purchased in cafés to reveal a six-fold difference in caffeine levels. The most caffeine in a single espresso was 322mg, while a further three contained over 200mg. Some of the differences come from levels of roasting – more intense roasting decreases caffeine levels, says Crozier.

Some of us may find it easier to limit caffeine consumption than others. “We have known for a long time that people’s consumption of drugs, including caffeine, has a genetic basis,” says Marcus Munafo, a University of Bristol psychologist. Using new genetic technology, the team is starting to identify genetic variants that account for differing levels of consumption. “We have been looking at specific genetic variants and using more precise measures of how much caffeine people consume,” he says. The aim is to find genetic markers for caffeine consumption and to see if they predict the risk of conditions like cardiovascular disease or stroke.

“Questions remain about the effects of dietary caffeine – that is, what effects are present at normal levels of consumption,” says Michael Keane. “For example, should caffeine be considered a risk factor in cardiovascular disease, given the evidence that we may not develop a tolerance to the blood pressure effects of the drug?”

While it’s unlikely to kill you, caffeine clearly can have negative effects on the body. If you’re worried about those effects, perhaps now is a good time to renounce, or at least reduce, your daily dose. ■

EMMA DAVIES is a science journalist with a PhD in food science

Find out more



BBC Scotland investigates the effects of caffeine on the brain.
<http://bbc.in/12yFTqk>

→ the effects of caffeine toxicity, explains Alan Crozier from the University of Glasgow’s School of Medicine.

In the UK and US, pregnant women are advised to keep daily caffeine consumption below 200mg per day, equating to about three cups of instant coffee. Recent research at Sahlgrenska Academy, Sweden, based on data from over 59,000 women who took part in the Norwegian Mother and Child Cohort Study, suggests that caffeine may cause decreased birth weight.

Health Canada, the national public health organisation, has recommended that children aged between 10 and 12 years have a maximum caffeine intake of 85mg per day. With just one can of energy drink taking children to this level, concerns are

rising over their consumption. A recent Swiss study on rats suggests that caffeine delays brain development during puberty by reducing deep sleep.

Energy drinks aren’t just dangerous for children, however. They

are commonly mixed with alcohol to give a phenomenon of being ‘wide-awake drunk’, reports the COT. The theory is that caffeine prevents people from realising just how intoxicated they really are and extends drinking time. In 2010, the FDA worked to withdraw caffeinated alcoholic beverages from the market, largely because of studies suggesting that ingesting caffeine and alcohol together may lead to ‘life-threatening situations’.

From December 2014, drinks containing more than 150mg per litre of caffeine – other than tea or coffee – will have to be labelled in the EU as having ‘high caffeine content. Not recommended for children or pregnant or breast-feeding women’. Yet there are no legal restrictions on the amount of caffeine that may be present.

HOW MUCH IS TOO MUCH?

So why isn’t caffeine labelled in absolute terms, in the same way as sugars or salt? People vary so much in their reactions to caffeine that a maximum figure could not be produced, says Richard Laming from the British Soft Drinks Association. “Even if there was a recommended intake, the proportion coming from soft drinks is small compared with that from tea and coffee.” With tea and coffee, the caffeine content varies widely from cup to cup so would be nigh on impossible to label.

The first documented drinkers of coffee were 15th Century Sufi monks in Yemen, though its use is thought to have begun much earlier in East Africa.

PHOTO: SCIENCE PHOTO LIBRARY

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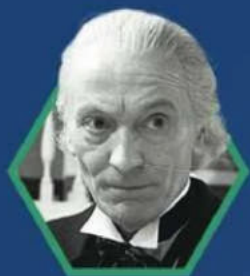


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ILLUSTRATOR: MAGICTORCH





WILLIAM HARTNELL

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THE FIRST DOCTOR arrived in a junkyard with his battered police box and it soon became obvious that he was not human – and the police box was far more than it seemed. At the heart of the story is time travel. However, real time travel is very different from a journey in the TARDIS.

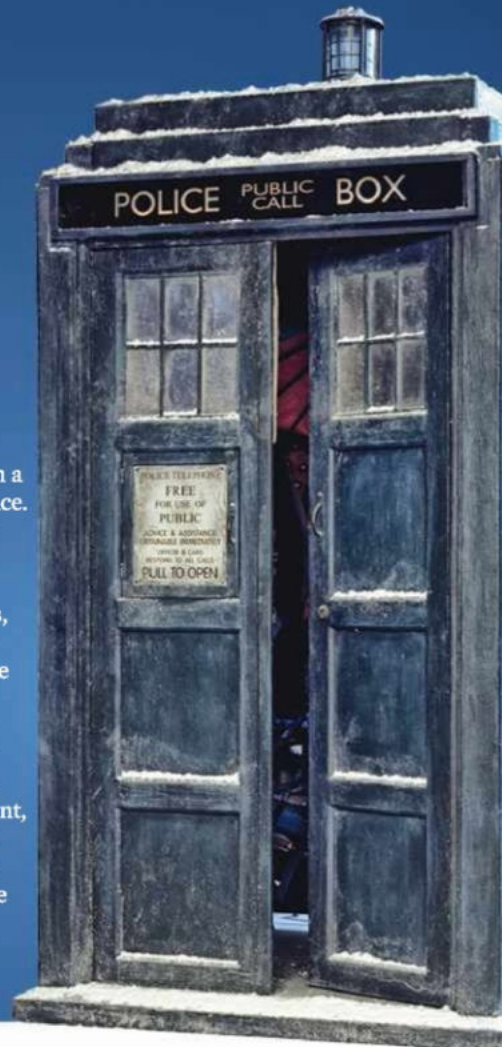
Travelling forwards in time is simple – all that's necessary is to move. The faster you go, the slower your time flows compared to home, so when you return, you will find yourself in the Earth's future – this is Einstein's Special

Relativity. Our best time machine is the Voyager 1 probe, which as it leaves the Solar System has moved 1.1 seconds into the future.

To obtain a sizeable effect means travelling at a good percentage of the speed of light. Voyager, at 17,000 metres per second, only manages 0.06 per cent of light speed. But forward travel is much simpler than getting into the past. To do this, General Relativity, the theory that explains gravity as a warp in space-time, is used. Gravity slows time down, but to make use of this requires

extreme engineering to open a wormhole in space, for instance.

But we're already masters of time because relativity influences sat-nav. GPS satellites are accurate clocks, broadcasting the time. They are corrected to allow for the impact of special relativity, slowing the clocks, but they also experience less gravity than something on Earth, so run fast. From their viewpoint, travelling to Earth would be a tiny shift to the past. If the clocks weren't corrected, the GPS accuracy would drift about 3km (2 miles) a day.



PATRICK TROUGHTON

1966-1969

REGENERATIVE MEDICINE

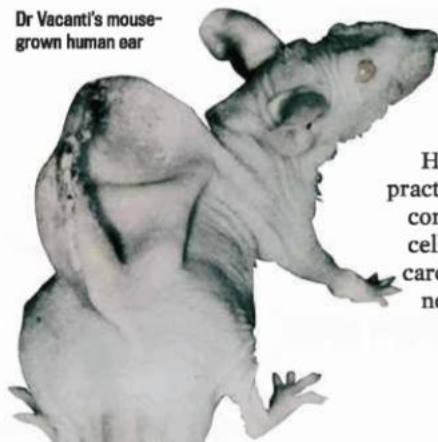
WHEN WILLIAM HARTNELL was replaced by Patrick Troughton, the change needed to be explained. The Doctor, we were told, could regenerate, coming back in a new – and in this case altogether more whimsical – form. We can't regenerate humans, but regenerative medicine may enable us to

grow replacement organs from a patient's own cells, overcoming transplant rejection and the donor waiting list. This is a long way from being practical. Though in 1997 Dr Jay Vacanti of the Massachusetts General Hospital grew a human ear on the back of a mouse, it is much harder to construct a complex organ than a simple structure

of cartilage. It also may be possible to use stem cells to reproduce the natural ability of the salamander to regrow limbs after damage.

However, the earliest practical examples may come from blood stem cell repairs to the cardiovascular and nervous systems.

Dr Vacanti's mouse-grown human ear



THE CYBERMEN

The Cybermen, first faced by Hartnell's Doctor, became more convincing in Troughton's time. Although such fearsome human/machine crossovers are unlikely to be made, in 2006 US defence agency DARPA put out a call for insect cyborgs. The first success was Michel Maharbiz's remote-controlled flying beetle, but now start-up Backyard Brains has a DIY cyborg cockroach controlled from a smartphone.



Own your own cyborg with a Backyard Brains RoboRoach kit



The Cybermen at their morning staff meeting



TARDIS

Fictional time machines date back to HG Wells, but the only serious scientific attempt to date is by American physicist Ron Mallett, who has dedicated his life to the concept. Ten-year-old Mallett wanted to go back to speak to his dead father. Professor Mallett now knows this isn't possible, as General Relativity time machines can't travel back beyond the point they were created. However, he still hopes to construct a machine producing a tiny displacement into the past.



THE DALEKS

These mutants inhabit robotic bodies and are efficient fighting machines. In the real world we are designing exoskeletons, metal and carbon fibre suits that amplify the wearer's movements to enable faster movement and heightened strength. DARPA in the US has an 'Exoskeletons for Human Performance Augmentation' programme. And unlike Daleks, they can climb stairs.

'Exterminate!'. When we don exoskeletons hopefully we won't develop a desire to wipe out all life in the Universe



JON PERTWEE

1970-1974

PIEZOELECTRIC EFFECT

THE THIRD DOCTOR, a dandy and action man, presented his companion Jo Grant with a Metabelis crystal as a wedding present. Though we have no equivalent of this crystal's ability to concentrate thoughts, real world crystals can generate electricity from pressure and move when a current is passed through them.

Demonstrated by Pierre Curie in 1880, piezoelectric devices soon moved into the home in the cartridges used to convert the wiggles of a record groove into electrical signals. They also turned up at the production end of the music business, providing pickups for guitars, and are used in a whole range of movement

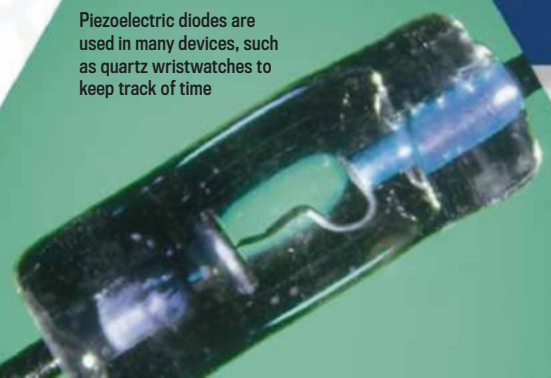
“Electrical signals make crystals flex and vibrate in everything from loudspeakers to inkjet printers”

sensors. Most impressively, the sparks used to ignite cigarette lighters and gas stoves are generated from a high-voltage piezoelectric crystal. Working the other way round, electrical signals make crystals flex and vibrate in everything from loudspeakers and inkjet printers to the quartz clocks in computers.

SONIC SCREWDRIVER

The Doctor's sonic screwdriver was first used by Patrick Troughton, but the third doctor took it from a literal screwdriver to a sonic tool. For years efforts have been underway to develop a sound equivalent of a laser, a 'saser'. This would enable far higher frequencies to be generated, transforming the detail available from ultrasound medical imaging.

Piezoelectric diodes are used in many devices, such as quartz wristwatches to keep track of time





TOM BAKER

1974-1981

COMPUTER NETWORKS

WITH HIS TRADEMARK scarf, Tom Baker transformed the role. During the fourth Doctor's time, viewers discovered more about his home planet, Gallifrey. Here, in a 1976 story, came a surprising discovery. The Time Lords had a computer system called the Matrix, a knowledge store 'virtual world' people could enter mentally, where battles could take place, and where the participants could be killed, resulting in the death of their real bodies. This might seem like a rip-off of the movie *The Matrix* if it hadn't been broadcast 23 years before.

This Matrix predates the term cyberspace, and though ARPANET, the predecessor to the internet, existed in 1976, it was just a linkage of large computers in universities. The

internet proper was arguably not implemented until 1982, while Tim Berners-Lee started the World Wide Web in 1990.

The Doctor's battles in the Matrix also had a touch of the computer game about them – and this too was apt timing. In 1976, the same year the Matrix appeared in *The Deadly Assassin*, a computer engineer working on ARPANET, Will Crowther, had a bold idea. Crowther wanted to keep his children amused, so he put together a text-based game that involved exploring a sequence of caves containing items like treasure and monsters. He

called it *Adventure*. There were already computer games, notably *Pong*, but Crowther's was the first that could be played across a network, starting a trend that has become huge in the computer gaming market.



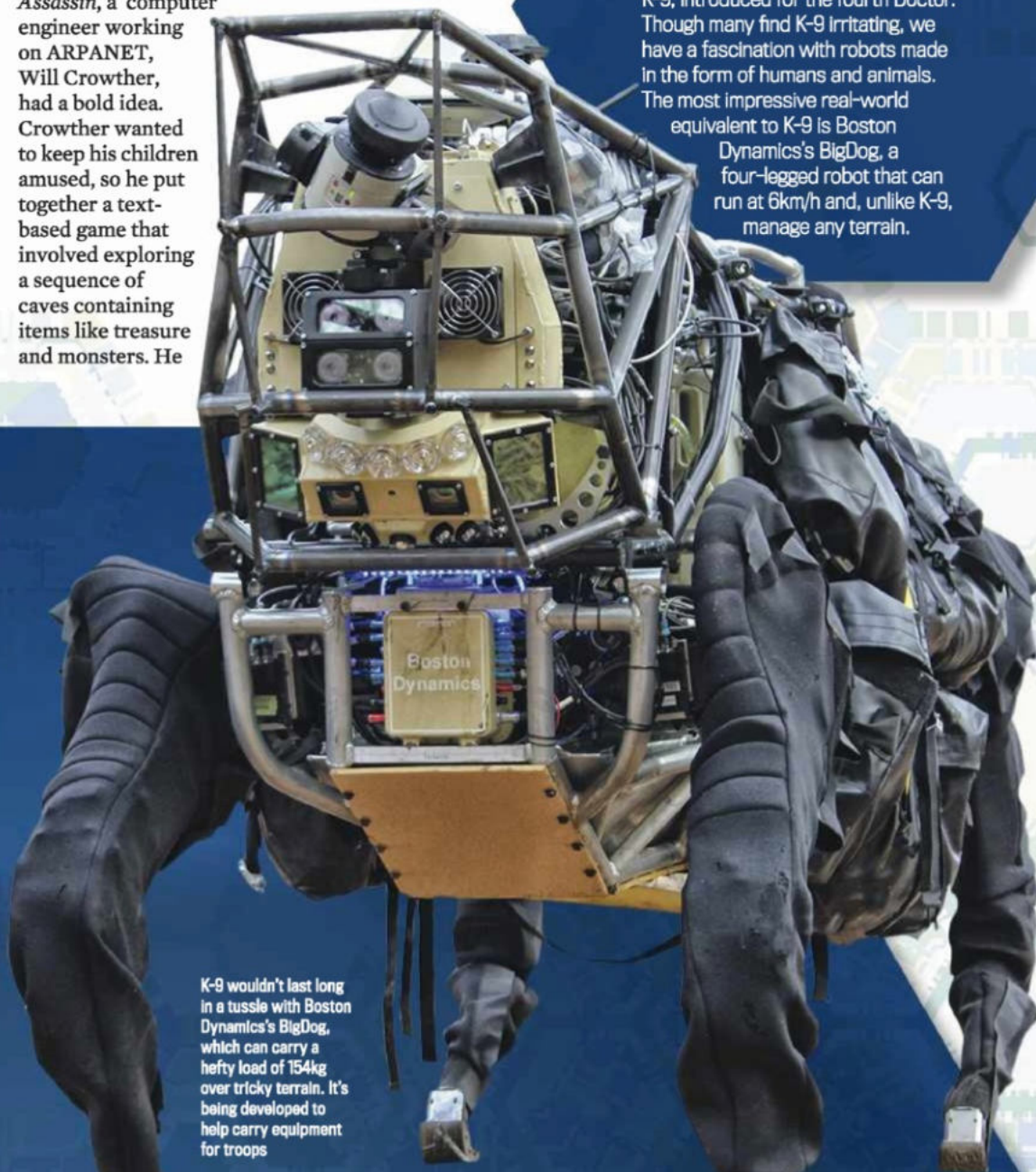
K-9

If there's one piece of *Doctor Who* kit that splits opinion it is his robot dog, K-9, introduced for the fourth Doctor. Though many find K-9 irritating, we have a fascination with robots made in the form of humans and animals. The most impressive real-world equivalent to K-9 is Boston Dynamics's BigDog, a four-legged robot that can run at 6km/h and, unlike K-9, manage any terrain.



DAVROS

It wasn't until 1975 that we met the Dalek's creator Davros. Apart from his Dalek wheelchair, the most striking aspect of Davros was his artificial eye. The first real equivalent came soon after in 1978, when maverick scientist William Dobelle gave a man limited sight by linking cameras on his glasses to electrodes embedded in the visual cortex of his brain.

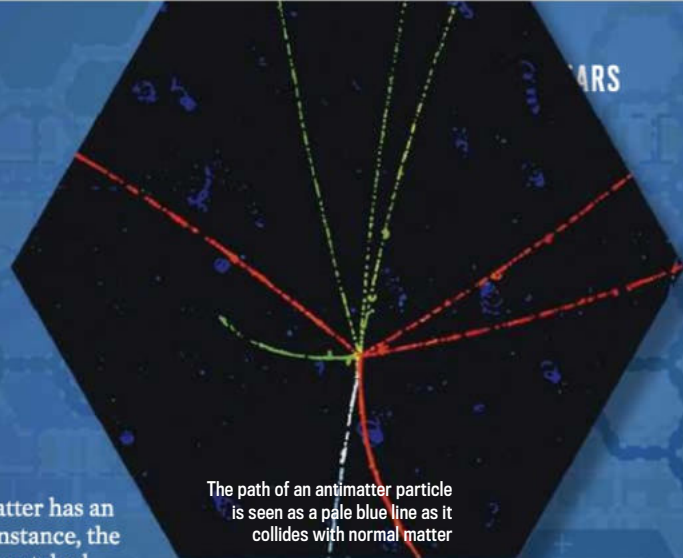


K-9 wouldn't last long in a tussle with Boston Dynamics's BigDog, which can carry a hefty load of 154kg over tricky terrain. It's being developed to help carry equipment for troops



PETER DAVISON

1981-1984
ANTIMATTER



The path of an antimatter particle is seen as a pale blue line as it collides with normal matter

PETER DAVISON'S FIFTH Doctor was a likeable, cricket-loving chap. He continued the revelations of Time Lord history, meeting the founder of this mysterious race, Omega. The fifth Doctor comes across Omega when the ancient Time Lord is released from exile in an antimatter universe. Although it sounds pure science fiction, antimatter is real.

Every particle making up matter has an antimatter equivalent, so, for instance, the negatively charged electron is matched with the positively charged positron. When matter and antimatter come together, they annihilate to produce vast amounts of pure energy. At the moment we can only make tiny amounts of antimatter. It remains a mystery why the

Universe seems to be almost all matter. One possibility is that there is a separate antimatter universe like Omega's, though it is more likely that there was more matter than antimatter created after the Big Bang.



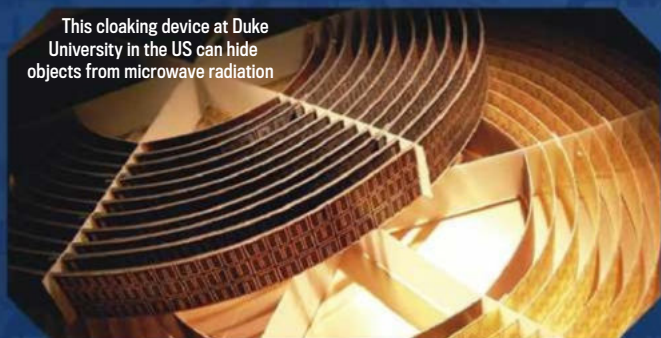
COLIN BAKER

1984-1986
METAMATERIALS



SYLVESTER MCCOY

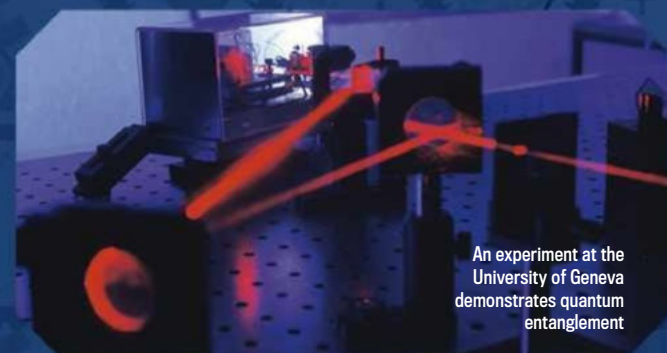
1987-1989
TELEPORTATION



This cloaking device at Duke University in the US can hide objects from microwave radiation

THE BOMBASTIC SIXTH doctor, played by Colin Baker, faced a new villain: the Rani, a renegade Time Lord with her own TARDIS. Unlike the Doctor's, the Rani's TARDIS had a working chameleon circuit, which made it blend into its surroundings. The closest we have to such a device are metamaterials. Normal materials bend light inwards as it goes from a less dense material into something denser. In metamaterials the light bends the opposite way. This means it's possible to produce the chameleon-like effect of an invisibility cloak, where light is bent around an object to hide it. It'll be a long time before a metamaterial can conceal a police box, but it may eventually be possible.

SYLVESTER MCCOY TOOK the reins as the quirky seventh Doctor and starred in the show's 25th anniversary season. This saw the return of an early Dr Who technology: the transmat. Such a matter transmitter is possible in reality on a tiny scale using quantum teleportation. Teleportation uses a quantum effect called entanglement to transfer the state of a particle to another one at a different location. Quantum teleportation may only be small scale, but it has been performed across considerable distances, including a demonstration of teleported particles across the river Danube in 2004.



An experiment at the University of Geneva demonstrates quantum entanglement



PAUL MCGANN

1996

INTERSTELLAR TRAVEL

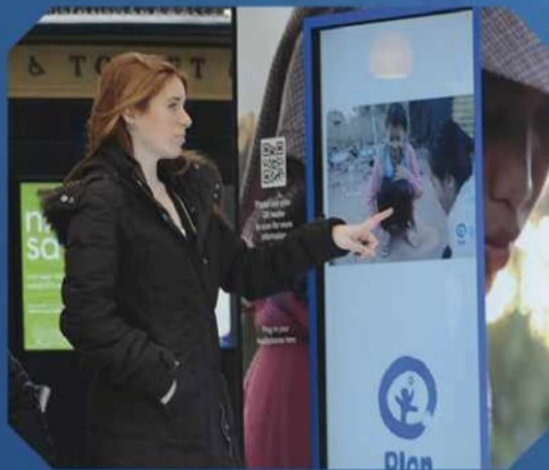
IT'S EASY TO miss Paul McGann, as the eighth Doctor only appeared in a single feature-length episode between the original series and its modern incarnation. At the heart of the story was a piece of Time Lord technology, the Eye of Harmony. The Eye is an artificial black hole that provides power for the Time Lords, used in this story as the driving force behind the TARDIS. We have never directly seen a black hole, and certainly don't know how to make one, but there is a hypothetical spaceship drive using a similar concept, called a Schwarzschild Kugelblitz drive.

Karl Schwarzschild was a German physicist who used Einstein's General Relativity to predict that massive stars could collapse to produce such

a concentrated mass that even light could not escape them. They were named black holes in the 1960s, but remarkably Schwarzschild dreamed them up in his spare time in the trenches in the First World War. The 'Kugelblitz' part is German for ball lightning. A Kugelblitz is a black hole made not of matter, but of light. Einstein showed that mass and energy are equivalent. If sufficient light energy is pumped into a small space it should create a micro-black hole. This could then be used to power a spaceship, because black holes give off a stream of radiation known as Hawking radiation. A Kugelblitz has never been made, but potentially an Eye of Harmony-type device could be created by zapping space with very powerful gamma-ray lasers.

Could we harness the power of a black hole to power a spaceship like the TARDIS?

"Eating will become separated from providing our energy needs, using nanotechnology to remove unwanted material"



It's not 'psychic paper', but a digital advert by Plan UK used facial recognition technology to determine whether a man or woman was standing in front of it and displayed different content



PSYCHIC PAPER

The Doctor's blank ID card, which says whatever the reader expects it to say, is still science fiction for now, but advertisements that appear differently to different people are on the way. Various companies make digital billboards with built-in cameras and facial recognition. So far, these are used to track which demographic pays most attention to a particular ad, but they could easily be used to send targeted ads. In fact, the charity Plan UK did just that last year, with an advert on bus shelters about gender discrimination that could only be seen in full by female viewers.



CHRISTOPHER ECCLESTON

2005 NANOTECHNOLOGY

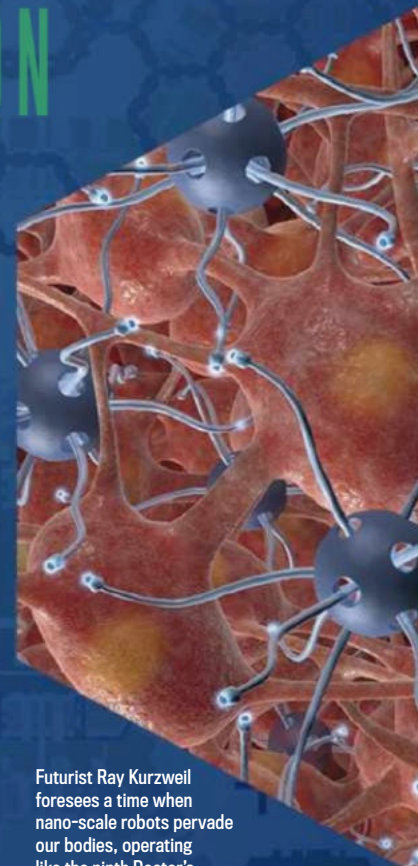
WHEN DOCTOR WHO returned in 2005, Christopher Eccleston gave the part a new grittiness. The series also introduced more complex companions, notably Billie Piper as Rose Tyler, and John Barrowman's Captain Jack Harkness. Harkness is a con man from the 51st Century. He owns a Chula spaceship, a wartime ambulance that carries a technology known as nanogenes, a swarm of near-invisible devices that

can enter a body and undertake medical repairs.

Nanotechnology – the use of materials and devices a few nanometres (billionths of a metre) in size – has been around a while, notably in sunscreens, which use nanoscale particles that prevent ultraviolet light getting through but are invisible to the eye. The ultimate dream though, just like nanogenes, is to have tiny robotic devices that enter a

body and interact directly with organs or remove cancers, cell by cell. Future-gazing technology millionaire Ray Kurzweil envisages a time when, for instance, self-propelled nanobots replace red blood cells as carriers of oxygen and carbon dioxide, meaning that the heart will no longer be necessary for survival. He has also suggested that eating will become separated from providing our energy needs, using nanotechnology to remove unwanted material, so we could eat whatever we liked and still have perfect nutrition.

As yet these miniature robots are science fiction, and the challenges are immense. It's not just a matter of making a conventional robot smaller – different forces become important at this scale. However, there is already research going on to realise the dream of medical nanotechnology. For instance, it would be desirable to use bacteria to release chemicals in the body, but the immune system attacks them. By enclosing the bacteria in a tiny capsule of carbon nanofibres, the bacteria are kept away from the body's defences but the **chemicals can pass through** the nanoscale gaps in the capsules unhindered.



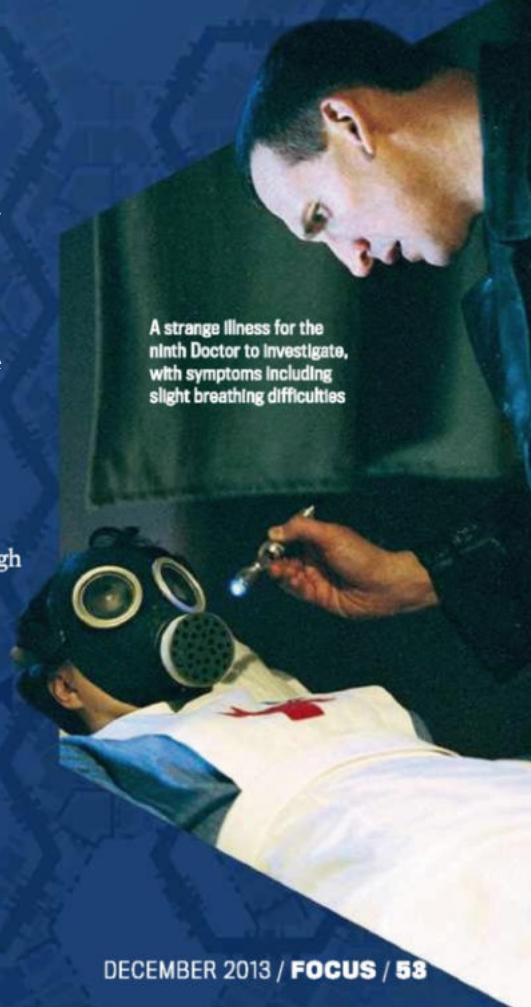
Futurist Ray Kurzweil foresees a time when nano-scale robots pervade our bodies, operating like the ninth Doctor's nanogenes

An unfortunate illness – still, you'd be able to survive a noxious chemical leak. Every cloud...

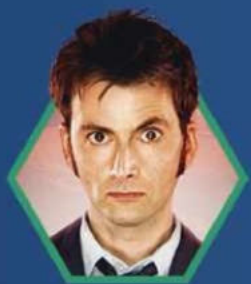


THE EMPTY CHILD

The 'empty child', a boy in a gas mask asking 'Are you my mummy?', crossed paths with the ninth Doctor. The child begins a plague where gas masks grow on patients' faces. This contagion is caused by an alien technology replicating a dead child in a gas mask to 'repair' injured humans. Scientists use a similar technique, molecular cloning, to produce large quantities of DNA. Enzymes snip out a desired DNA sequence, which is then introduced to bacteria. As the bacteria reproduce they make multiple copies of the DNA sequence, which can then be harvested for use in experimental studies.



A strange illness for the ninth Doctor to investigate, with symptoms including slight breathing difficulties



DAVID TENNANT

2005-2010

THE ZENO EFFECT

THE TENTH DOCTOR proved more laid-back than his predecessor, though David Tennant faced the scariest of the modern monsters: 'Weeping Angels' (pictured on p56). These statues remain motionless but move when not observed, closing in on you in the blink of an eye to reveal a monstrous set of teeth. Weeping Angels cover their eyes to avoid seeing each other, the deadly statues being inspired by the childhood game Grandmother's Footsteps. What's more, they have a surprising reflection in reality with the quantum Zeno effect.

Zeno was an ancient Greek philosopher who believed

change and motion were illusions. He pointed out that an arrow in flight didn't appear to be moving if you looked at it in any particular moment of time. Zeno's name was picked up by George Sudarshan and Baidyanath Misra, physicists working at the University of Texas, to describe a weird quantum phenomenon.

At the heart of quantum theory, the science governing very small particles like atoms and photons of light, is probability. What happens to quantum particles isn't definite, but down to chance. This was why Einstein hated the theory and made his famous remarks about God not

playing dice. A good example of this is that when a particle undergoes radioactive decay, you can't say when it will decay, just the probability of the decay happening.

However, the duo noticed something very strange. If you make a measurement of the particle, it won't decay at that point in time. And if you keep looking regularly enough, you can prevent it from decaying for as long as you like – this is the quantum Zeno effect. Like a watched pot never boiling, or a Weeping Angel never moving while being looked at, unstable quantum systems like a decaying atom really do wait to act until you look away.



THE MASTER

The tenth Doctor faced a new incarnation of the Master, his nemesis since 1971. The Master is elected Prime Minister using subliminal control. Such messages are not noticed consciously, but affect the brain. Flashing up a logo can encourage a thirsty person to desire a particular drink, for instance, but it isn't possible to fool someone into thinking they are thirsty – or to like something they didn't already.

SUPERPHONE

Since the series reboot, companions have had a 'superphone' – a mobile, modified to work across time and space. The tenth Doctor dubbed this 'universal roaming'. As yet we don't have the same problem, but we do experience time lags when communicating with probes in space, due to the finite speed of light. The Curiosity rover on Mars takes around 20 minutes to respond to a command, while the signal from Voyager 1 as it leaves the Solar System takes around 17 hours to reach us.

PHOTO: BBC X4, GETTY, NASA

It takes 20 minutes for a signal to reach NASA's Curiosity rover on Mars. If only we had 'universal roaming' technology to speed things up



MATT SMITH

2010-2013

STRING THEORY

“String theory replaces the zoo of particles used to explain matter and forces with a single fundamental element”



THE SONTARANS

The pudding-headed Sontarans have been regular villains since Jon Pertwee's time. With the eleventh Doctor a Sontaran, Strax, became one of the Doctor's allies. Sontarans are cloned, explaining their near-identical looks. A clone is produced from the genetic material of a single 'parent', which it was originally assumed would make it identical. But in reality, environment plays a large role in the development of an organism. This is why the first cloned cat 'Cc' was a tabby, despite her 'parent' being a calico.

Cc, which is short for 'Carbon Copy', is the world's first cloned pet



THE TARDIS HAS always been bigger inside than out. It's a feature that the sometimes clown-like eleventh Doctor, played by Matt Smith, often refers to, turning 'It's bigger on the inside' into a running gag. That is until thrown by new companion Clara commenting 'It's smaller on the outside.' The usual explanation is that the TARDIS is 'dimensionally transcendental.'

A transcendental number (like pi) is one that can't be represented exactly by a finite equation. Here it implies that the spatial dimensions inside are different to those outside.

Something similar crops up in string theory, and its big brother M-theory. These are attempts in physics to combine the forces of nature, bringing together the otherwise incompatible quantum theory and General Relativity. String theory replaces the zoo of particles used to explain matter

and forces with a single fundamental element: the string. This chameleon-like, one-dimensional object produces all the familiar particles through its different vibrations, either as a closed or open loop.

This simplifies things wonderfully, but comes at a price. String theory only works with nine spatial dimensions plus one of time. There are several variants of string theory that are combined to make M-theory, but to do this requires adding yet another space dimension. An obvious problem is that we don't see nine or 10 space dimensions, we see just three: length, height and width. The argument goes that the 'extra' dimensions are curled up so small that we can't detect them.

It would be rather neat if the 'transcendental' dimensions used by the TARDIS turned out to be some of string theory's spares.

GRAVITY GLOBE

Floating gravity globes containing an 'antigravity' substance are key to an eleventh Doctor episode. No known substance blocks gravity – if one existed, it could be used to make a perpetual motion machine, turning a water wheel that has gravity blockers on one side of each paddle. However, some theories suggest that antimatter could be repelled by the gravitational force. Because we've never made enough antimatter to be able to test it, we don't yet know how it responds to gravity. Turn to p56 for the latest experiment to investigate antigravity.

BRIAN CLEGG is a science writer and the author of *Build Your Own Time Machine: The Real Science Of Time Travel* (Duckworth, £8.99)

Find out more



Prof Brian Cox presents *The Science Of Doctor Who* on BBC Two on 14 November.



The *Doctor Who* 50th anniversary episode 'The Day Of The Doctor' airs on 23 November on BBC One.



STEPHEN BAXTER

DOCTOR WHO'S FUTURE VISIONS

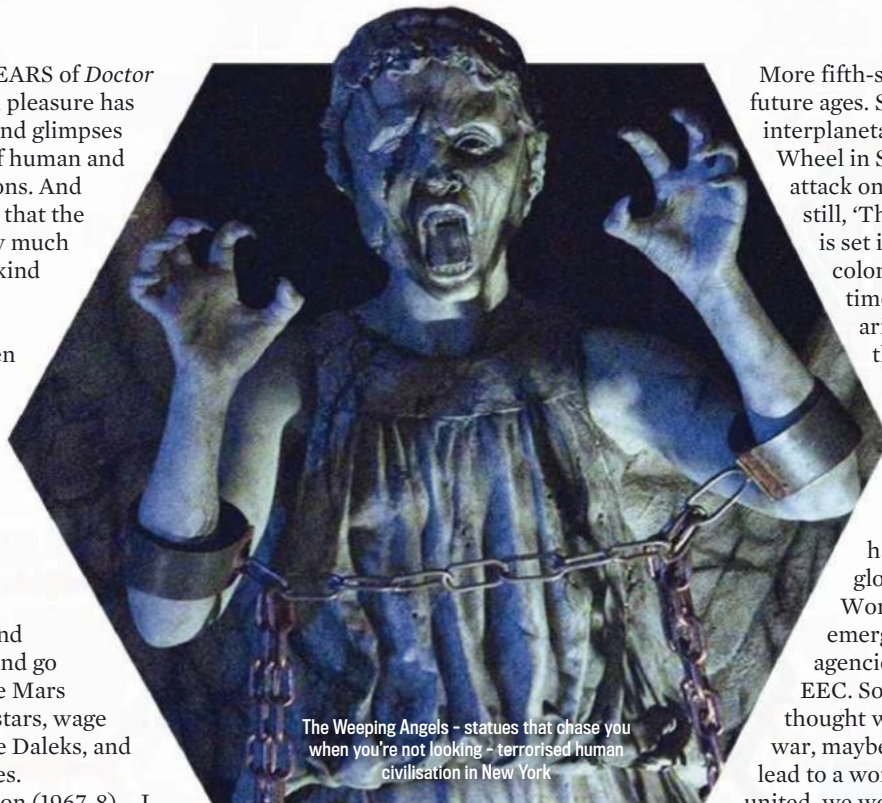
The show's storylines have always been a product of the age in which it was born

OVER FIFTY YEARS of *Doctor Who*, an added pleasure has been background glimpses of the future of human and alien civilisations. And it's remarkable to reflect that the show has depicted pretty much the same future for mankind consistently since 1963.

Well, almost. *Who*'s creators have always been primarily focussed on telling the next story, rather than on overall continuity. But if you think back even over recent seasons, you'll know the kind of future I mean. After a past and present plagued by alien incursions, criminality and war, humans will unite and go on to explore planets like Mars and the worlds of other stars, wage war against races like the Daleks, and found interstellar empires.

Consider the fifth season (1967-8) – I remember it well as a 10-year-old. In 1963, thanks to UFO scares and the radio search for alien signals, the notion that aliens existed, and maybe were here already, was in the air. Thus in 'The Abominable Snowmen', set in the 1930s, a Tibetan monastery has been taken over by the Great Intelligence (who would return in the 2012 Christmas special). In 'The Web of Fear' set 40 years later, the Intelligence's robot Yeti rampage in the London Underground. In the near future, science and engineering would advance. 'Fury from the Deep' features North Sea gas extraction, and in 'The Enemy of the World', sunlight is harvested to feed a hungry world: a typical 1960s ambition.

"Over 50 years *Doctor Who* has become a kind of ark bearing the hopes and fears of its creators"



The Weeping Angels – statues that chase you when you're not looking – terrorised human civilisation in New York

More fifth-season stories illustrate future ages. Set a century later, when interplanetary travel is routine, 'The Wheel in Space' is about a Cyberman attack on a deep-space station. Later still, 'The Tomb of the Cybermen' is set in an age of interstellar colonisation. On the longest of timescales, exotic possibilities arise. In 'The Ice Warriors', the Earth has slumped into a new Ice Age.

That rough future framework was a product of the age in which *Doctor Who* was first created. The world had just seen a mighty global struggle, the Second World War, followed by the emergence of multinational agencies like the UN and the EEC. So in the future, it was thought we might face a fresh war, maybe nuclear, that would lead to a world government. Then, united, we would move out into space. *Doctor Who* has striven to maintain

continuity with its past, so the same kind of future is portrayed today. *Who* season 33, broadcast in 2012, featured two stories of aliens troubling humanity in the past, a cyborg in the Old West in 'A Town Called Mercy', and the Weeping Angels in 1938 New York in 'The Angels Take Manhattan'. 'The Power of Three' is a modern-day alien invasion story, complete with UNIT, a UN military arm involved in *Who* stories since the 1960s. Finally, the season close 'Asylum Of The Daleks' is a far future story set in deep space. The stories from the two series, produced as far apart as 1968 and 2012, fit into the same kind of future history, of alien incursion, technological growth and expansion into space.

Projected from today, our assumed future might include eco-crash and resource wars, perhaps resulting in poverty and social division, such as featured in *The Hunger Games* or *Elysium*. But the very different future as seen from 1963 is still embedded in *Doctor Who*. Over 50 years *Doctor Who* has become a kind of ark bearing the hopes and fears of its creators into an age they could probably barely have imagined. Even the future has a past. ■

STEPHEN BAXTER is a science fiction writer. His latest novel is *Proxima* published by Gollancz.



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V SERIES

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ADVERTISEMENT FEATURE

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Canon PowerShot G16 specifications

- > 12.1-megapixel CMOS sensor
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- > f/1.8-2.8 28mm lens with 5x optical zoom
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Can't decide between the convenience of a compact camera, or the hands-on control and high-end features offered by a DSLR? You don't have to – the PowerShot G16 gives you both. Based around a 12.1-megapixel CMOS sensor and a DIGIC-6 image processing chip, the PowerShot G16 is powerful and fully-featured, allowing you to take pictures to a professional standard, yet it's small enough to fit in your pocket. By offering a host of features and controls it takes the pain out of capturing that perfect shot.

Fantastic star trail images like the one seen here, for instance, can be easily created on the PowerShot G16 by selecting Star mode, choosing the shutter speed and number of shots and leaving the camera to shoot continuously for up to two hours. At the end of the session, the PowerShot G16 will create a composite image for you automatically. Star mode will also capture great single shots of the night sky, applying automatic image enhancement so that the stars truly shine.

You're in control

The beauty of the PowerShot G16's design is that you'll find the full range of features and controls you'd expect from a DSLR camera, including manual focus, ISO adjustment up to 12,800, full aperture and shutter speed controls, exposure compensation, automatic bracketing and neutral density filtering. Plus, there's an optical viewfinder and a hotshoe for an additional flash unit. They don't call this "the compact for experts" for nothing!

If you're still learning, however, then the PowerShot G16 also features the easy-to-use shooting modes. The camera offers superfast customisable autofocus with face detection, dedicated one-touch settings for taking photos at night, in snow or underwater, fireworks and star modes, and an array of built-in image effects including fish-eye, sepia, soft-focus and too many more to list here. Versatile doesn't begin to cover it...

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Want to photograph a fast-moving subject? Whether it's a cheetah spotted on safari or your kids at



their school sports day, the PowerShot G16 has it covered. Continuous shooting at up to 12.2 shots per second means you can take a selection of images, then select the best ones.

Perfect close-ups

When you want to get really up close and personal, the PowerShot G16's macro facilities are second to none. Drops of dew on the petals of a rose or the splendid colour and intricate patterns of a butterfly's wing... these things are within your grasp thanks to the PowerShot G16, which will let you get closer to your subject than you ever thought was possible.

Connect without cables

Transferring and sharing your pictures is quick and easy, thanks to the PowerShot G16's Wi-Fi capabilities. Use Wi-Fi to send pictures to your computer or smartphone, print them wirelessly or geotag them with GPS data from your phone. You can also upload them to albums on Canon's own cloud service CANON iMAGE GATEWAY, or send them via CANON iMAGE GATEWAY to Facebook, Twitter, YouTube and Flickr – all at the touch of a button.

BRITAIN'S BIGGEST MAGNIFYING GLASS

PHOTO: DIAMOND LIGHT SOURCE



The UK's Diamond Light Source is at the forefront of biological research. **Matthew Chalmers** visits the particle accelerator to see this 'giant microscope' in action

PROTRUDING HORIZONTALLY from a thick concrete wall is a chest-high tube that looks like a large gun barrel. Behind the wall lies a £250m particle accelerator, half a kilometre in circumference, which fires intense beams of X-rays down the tube. A coffin-sized steel case packed with specialist mirrors focuses the beam down to a tiny spot 10 billion times brighter than the Sun at the mouth of the tube. There, next to a small pipe hissing chilled vapour, a large robotic arm fixed to a granite slab on a reinforced concrete floor waits to load specimens into the path of the beam.

We wouldn't be standing here if the machine were switched on. "You'd pretty

much die from acute radiation poisoning," explains Dr Danny Axford, senior support scientist at Diamond Light Source near Oxford in the UK.

The sights and sounds of Diamond's heavy-duty 'beamlines' – 23 of which fan out from the accelerator, housed in hutches made from several tons of lead – are a world away from the white coats and test tubes of a typical biology lab. After all, particle accelerators are normally concerned with such things as Higgs bosons.

Yet here in the firing line of Diamond's 'I24 beamline' dedicated to biological research, scientists are placing the delicate molecules that govern our cells, not to mention the viruses that try to hijack them. This giant silver doughnut in the

The Diamond Light Source in Oxfordshire houses a particle accelerator in a doughnut-shaped structure that would cover six football pitches



➔ heart of rural England is providing biologists with images of the 3D atomic-scale structure of life's basic units, opening up a new era in drug design. "We want to be the best place in the world for doing this stuff," says Axford.

A GIANT MICROSCOPE

Diamond is a synchrotron, not to be confused with the X-ray machines in hospitals. Those more familiar devices use a much more dilute X-ray beam that is easily blocked by dense bone tissue. Synchrotrons fire intense beams of high-energy X-rays straight through a sample, acting as powerful microscopes. Since X-rays have a wavelength about 1,000 times shorter than that of visible light, they are ideal for mapping atomic detail. When X-rays strike an object they are scattered by electrons in its chemical bonds to produce a characteristic 'diffraction pattern' made up of spots of different intensities. This enables researchers to work out its atomic or molecular arrangement.

The idea emerged from physics a century ago, and in 1953 enabled Crick and Watson to decode the famous double-helix structure of DNA molecules. But synchrotrons, which grew out of particle physics research during the 1960s, have

"It's providing biologists with images of the 3D atomic-scale structure of life's basic units"

taken the technique to new heights. Indeed, they have become a must-have tool for tens of thousands of scientists who study anything from advanced concrete to the chemical reactions ruining priceless works of art.

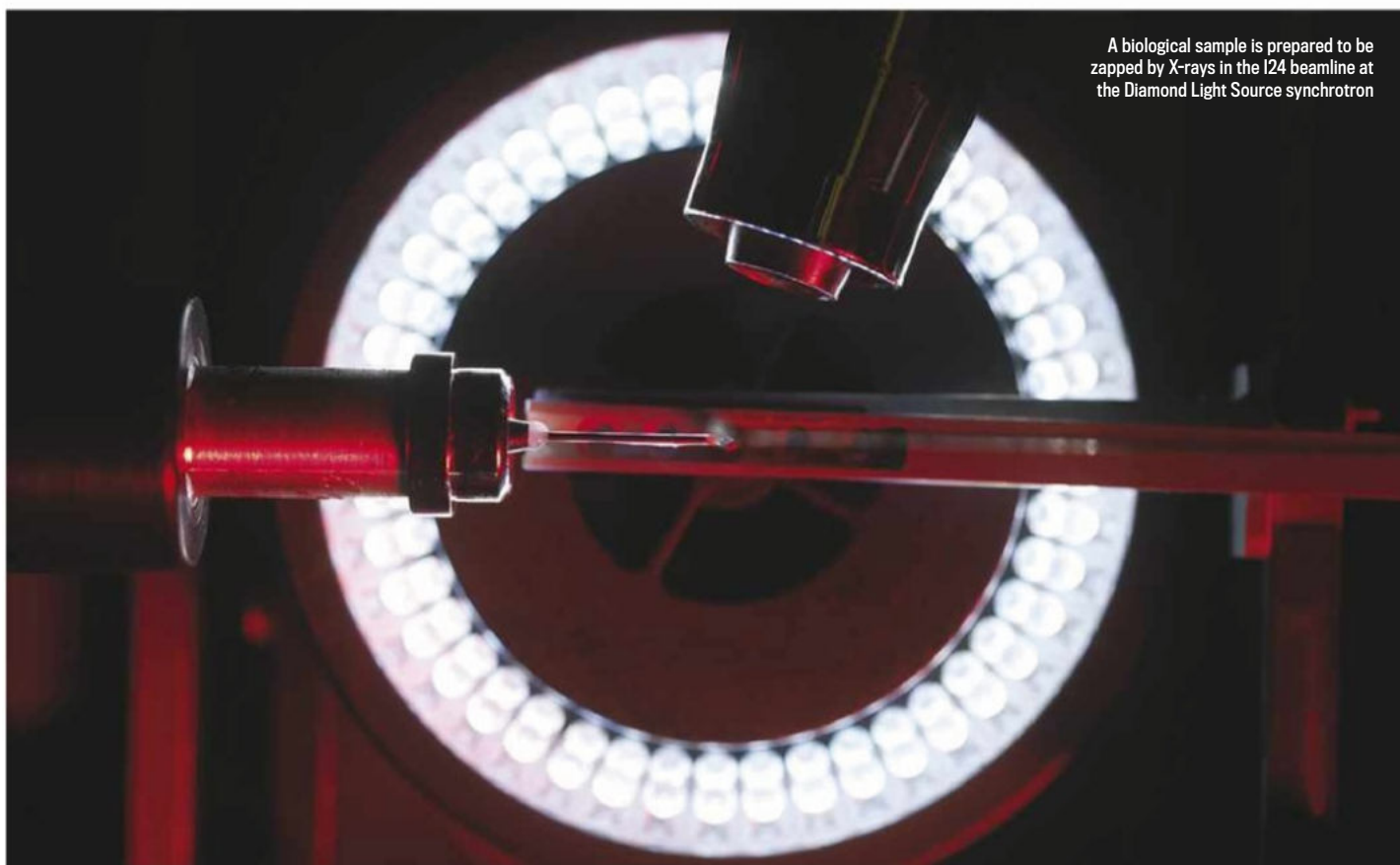
In biology, where structures are tricky to image because they are more freeform than the rigid atomic lattices of solids, synchrotrons allow scientists to understand how the physical structure of a molecule influences its function. The complex proteins that biologists are interested in today would yield nothing but an amorphous blob were researchers to view them using Crick and Watson's simple X-ray kit.

Recently, scientists at Heptares Therapeutics in the UK used Diamond's I24 beamline to crack the structure of a type of 'G-protein coupled receptor' (GPCR) in our pituitary gland that controls our response to stress, offering the possibility of better treatments for anxiety and depression. These complex structures are embedded in our cell membranes. They subtly change shape when certain molecules bind to them, triggering a physiological response such as the retina's reaction to light or the ability of the nose to detect odours. Almost a third of modern drugs act on the processes stimulated by GPCRs, and last year's Nobel Prize for Chemistry went to scientists who had used synchrotrons to crack one.

"We chose Diamond because it has a very intense, micron-sized beam. Plus they have a great detector, and it is only an hour and a half down the road," says Dr Andrew Doré of Heptares. "We've solved more than 35 structures there, but this was the big one."

The breakthrough was the result of visiting Diamond roughly once per month for a year and a half, each time going through up to 200 samples during day-long shifts. Each crystal loaded into the I24 beam is about the size of a grain of talcum powder and contains billions of individual GPCRs which, without careful

A biological sample is prepared to be zapped by X-rays in the I24 beamline at the Diamond Light Source synchrotron



INSIDE THE SYNCHROTRON

Before X-rays hit a tiny target they are first produced by a particle accelerator and focused down a tube

The Diamond Light Source synchrotron is a huge ring of machinery geared to delivering intense beams of X-rays



1 Linear accelerator
Electrons stripped from a hot tungsten wire are accelerated to high energies by a short linear accelerator, or LINAC.

2 Booster
A small athletics track-shaped ring called a booster accelerates the electrons to much higher energies.

3 Storage ring
Electrons are inserted

into the storage ring where they are guided by magnets, emitting synchrotron radiation as they circulate in a vacuum. All charged particles emit electromagnetic radiation when deflected by a magnet, and for electrons travelling at near-light speeds the radiation is emitted in the X-ray region of the spectrum.

4 Insertion device
At some 20 points

around the ring, electrons encounter an array of alternating 'north' and 'south' magnets arranged like the teeth of a comb, which causes them to wiggle and emit strong synchrotron radiation.

5 X-ray optics
X-rays pass through a shutter and down the beamline, where X-ray mirrors and other elements allow properties of the beam

to be tailored to suit specific scientific needs.

6 End station
Tens of metres downstream from the storage ring, X-rays finally hit the target where they are scattered by electrons in the sample, picked up by powerful digital cameras.

7 Control cabin
Scientists monitor and record the results of their X-ray-blasted samples here.

preparation, can be damaged or exist in a different chemical state – reducing the quality of the diffraction pattern. The team finally nailed the structure last summer. “There were three of us working 24 hours straight and it was a pretty great moment,” says Doré.

The diffraction data revealed a nanoscale pocket in the protein that could be blocked by a designer molecule that slots into it, inhibiting the protein’s function. It’s a more direct way to design drugs than traditional trial-and-error approaches, reducing the chances that

a new drug will cause unexpected side effects. This approach is being applied to other GPCRs, allowing researchers to design drugs for Alzheimer’s disease, schizophrenia and diabetes (see ‘Targeting disease’, p58).

The occasional bottle of champagne dotted around the 124 control cabin is testament to such moments of success, but the atmosphere on the beamlines can become tense if sleep-deprived users face going home without the data they wanted. Beam-time at Diamond costs thousands of pounds per shift and has

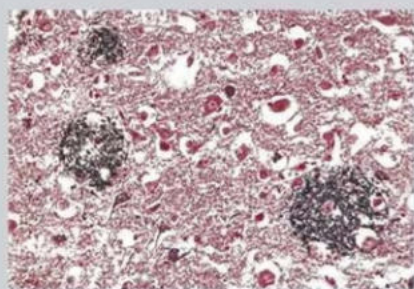
to be booked months in advance, so it’s vital that local experts such as Danny Axford are on hand to support visiting scientists. He once watched a user pour a flask of liquid nitrogen down a sink, breaking it into pieces, but things usually run smoothly. “We try to make it as simple as possible because increasing numbers of biologists are turning to synchrotrons and the equipment doesn’t look very user-friendly,” he says, adding that users can even send their samples by courier and load them into the beam remotely with a few clicks of a mouse. ➔

TARGETING DISEASE

The world's most deadly diseases are being probed at a molecular level to help develop new treatments

Alzheimer's

One of the difficulties in understanding Alzheimer's is that irreversible brain-cell death occurs before the condition has been diagnosed. Several groups are using Diamond to carry out research that will help clinicians develop markers to spot Alzheimer's at a much earlier stage, and to get a better handle on the biochemical processes responsible for the disease.



Alzheimer's reveals itself as black plaques in otherwise healthy brain tissue

Cancer

Researchers use Diamond to probe some of the processes that drive cancer – for instance by deciphering the shape of proteins known to be implicated with the disease. Inherited faults in a protein called FANCL that is involved in repairing damage to DNA, for example, can increase the risk of several types of cancer and help cancer cells become resistant to chemotherapy.

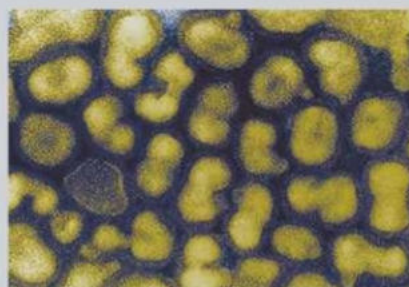
Diabetes and osteoporosis

By 2025 it is estimated that five million people in the UK will have diabetes, mostly Type 2 diabetes. Thanks to the

recent discovery of the stress receptor protein, scientists from Heptares Therapeutics now have a template that can be used to help work out the structure of other receptors in the same family, which includes those underlying Type 2 diabetes and also osteoporosis. This can be used to design better treatments.

Flu

Viruses such as influenza and so-called 'superbugs' evolve incredibly rapidly, so each new strain requires a new approach both in terms of protecting people with vaccinations and treating patients who have become infected. Diamond gives scientists rapid access to its facilities and therefore has an important role to play in our response to new flu strains and other emerging viruses.



The influenza A virus; flu strains like this are being targeted by Diamond

HIV

Viruses infect us by inserting copies of their genetic material into our DNA, and scientists have used Diamond to advance our understanding of how HIV and other retroviruses infect human or animal cells. Fundamental knowledge from the synchrotron will allow the design

of better drugs for fighting AIDS, but may also have an impact on pioneering treatments such as gene therapy to treat disorders involving defective genes.



The HIV virus (green) can be seen budding from a lymphocyte (red), a kind of white blood cell

Malaria

Diamond is being used to get a detailed picture of the novel proteins that make up the parasites that infect us and cause the debilitating and life-threatening symptoms of malaria and other tropical diseases. Armed with detailed pictures of the perpetrators, better treatments can be designed to guard against and treat these serious diseases.

Polio

In order to eradicate polio we need to design a vaccine that does not make use of the live virus. Following a breakthrough at Diamond Light Source in 2013, when a UK team showed that a safe empty-shell vaccine could be developed for foot-and-mouth disease, scientists are now using Diamond to investigate whether a similar vaccine for polio could be developed.



Biologist Prof Dave Stuart of the University of Oxford is director of life sciences at Diamond and is hooked on what the machine can tell us about viruses. "Watson and Crick tried to sort out problems with viruses shortly after their famous DNA work, but really the tools they had were hopeless," he says. "You can only do it effectively with a synchrotron."

Viruses far outnumber all other life forms – a glassful of seawater will contain billions of them. Most are benign, while others have co-evolved with their hosts

into efficient cell-destroying machines. Biologists have only scratched the surface of the virus world, says Stuart, but synchrotrons are beginning to allow him and others to piece together the evolutionary tree of these primitive entities. The speed at which viruses evolve makes it impossible to use genome-based techniques to trace their family tree. But synchrotrons can reveal structures that viruses have in common, which show some to be more related than others and has important implications for tackling certain diseases.

Earlier this year, Stuart led a study at I24 that demonstrates a new way to produce vaccines for foot-and-mouth disease – one of the most infectious viruses known. While not dangerous to humans, the virus can devastate livestock. Being extremely tightly controlled, it is difficult to carry out experiments with the live virus. But Stuart and his team found that a live foot-and-mouth virus is structurally identical to a dead one.

The live foot-and-mouth virus comprises a protein shell that encases the viral genome, which is the part that hijacks

A patient receives radiotherapy for a brain tumour, a desktop-sized synchrotron would be handy for hospitals

SHRINKING SYNCHROTRONS

The race to reduce stadium-sized technology to the size of a table

Synchrotrons are revolutionising the way scientists design drugs and fight diseases, but with a price tag of hundreds of millions of pounds and a footprint the size of several football pitches, you're not likely to see one in your local hospital any time soon. Hospitals use linear electron accelerators both for imaging and for destroying tumours, and these would be the first areas to benefit from compact synchrotron technology. Researchers are trying to come up with smarter ways to accelerate particles that would allow compact synchrotron

sources small enough to fit inside a room or even on top of a table. An example is ThomX at the Laboratoire de l'Accélérateur Linéaire in Orsay, France, which is scheduled to be operational in 2016, while another can be found at the Centre for Advanced Laser Applications in Garching, Germany.

Research into the shape and size of proteins and other biological units demands such high-energy beams and precise control, however, that it will likely remain the work of major national facilities for some time.

'X-ray lasers', which are several kilometres long and fire X-rays billions of times brighter than a synchrotron at a rate of up to 20,000 pulses per second. By launching a sample into the path of a single unimaginably extreme pulse, a rich diffraction pattern can be obtained just in time before the next pulse vaporises the sample. This could reveal more subtle structural information than is possible with the much longer exposure times of a synchrotron. Stuart recently visited one of the world's few operational facilities in California, where his group took a snapshot of a virus attacking a human cell.

X-rays might lay bare biology at the atomic level, but this physics-based approach can only take us so far. "You can try to break a thing down into its basic components, but ultimately evolution is a random process so everything that can happen will happen," says Stuart. "Biology isn't necessarily harder than physics," he says, "it's just completely different." ■

MATTHEW CHALMERS is a science writer with a PhD in physics

Find out more



Listen to an episode of *Discovery* that looks at the work of scientists operating the Diamond Light Source. <http://bbc.in/pHlgBP>

the reproductive machinery of a cell in order to self-replicate. Stuart and co-workers showed that a synthetic version comprising only the protein shell triggers the same immune response and is therefore ideal for developing vaccines safely. "We expected that the shells might have filled up with something but they don't, so there is no chance of infection," says Stuart. The team is now applying the technique to other viruses from the same family, including polio. If an inactive vaccine against the virus were available, it raises the prospect of a polio-free planet – just like the successful eradication of smallpox 30 years ago.

X-RAY LASERS

That said, biologists might have to turn to even more fearsome machines to truly fathom the stuff of life. Synchrotrons face competition from a new breed of



Prof Dave Stuart is using the Diamond Light Source synchrotron to study viruses in the hope of finding vaccines for diseases like polio and foot-and-mouth



ADVERTISEMENT

Style OVER substance?

“Quite remarkably, many people today and probably a majority of teens and late teens, are listening to a considerably lower quality level of music than their peers back in the 1970’s”

Have advances in technology driven the desire for convenience and quantity at the expense of quality?

Listening to Music – the Benefits

There have been many studies carried out over the years that have shown remarkable benefits for mankind through listening to music. It is an activity that is intrinsic to all cultures and is one of the few that involves using the whole brain. Listening to music is now often used for various therapeutic purposes because it is believed to improve memory and intelligence, improve physical development and coordination, reduce stress and blood pressure, and even reduce levels of pain.

However, music can also be irritating if it's too loud or distorted, or if it distracts from other activities we are involved in. Most of the studies have been carried out using a reasonably good quality of musical reproduction. Quite remarkably, many people today and probably a majority of teens and late teens, are listening to a considerably lower quality level of music than their peers back in the 1970's. Back then a basic hi-fi system, often consisting of just a turntable, amplifier and a pair of speakers, was a 'must have'. Students going off to university would make it a priority to set themselves up with a decent hi-fi system – and the quality was, in retrospect, surprisingly good.



Quality vs Quantity

How different it is today where advances in technology have driven the desire for convenience and quantity at the considerable expense of quality. For many young people especially, the iPod, MP3 player or mobile telephone, connected to a pair of in-ear headphones, is their primary source of listening to music. The problem with this is that low-grade reproduced music is not going to deliver any significant beneficial outcomes for the listener. Probably the opposite will be true.

Low-grade music in this context is the result of two main factors, a) the delivery system (the hardware) and b) the source material (the 'music'). Although the amplification section of the mobile device is a technological wonder, it's not hi-fi! Nor are in-ear headphones. They can't hold a candle to the stereo-typical system from the 1970's. As far as the source material is concerned, it's being over-generous to call it music if it's a typical MP3 or AAC (the iTunes default format) download. These are both highly compressed formats with the most popular download speed of 128 kbps being about one-eleventh the size of a full resolution CD track (1411 kbps), so the quality is inevitably far inferior. Information is irretrievably lost and the full dynamic range is lacking. Using an iPod while jogging does not really raise a quality issue but playing low-resolution tracks through, for example, an iPod docking station that feeds into a decent hi-fi system, is a disaster area. It is very poor quality made louder and this even affects the type of music listened to. For example, most classical recordings downloaded as an MP3 or AAC file are a complete waste of time because there is so

much information missing, all the complexities of the music are lost, and the recordings are reduced to just the essence of a tune.

Future of Recorded Music

If convenience has trumped quality for many people, we must ask what the future prospects are of maintaining high quality music recordings. Fortunately audiophiles, or hi-fi connoisseurs, or perhaps most accurately described, music lovers, continue to drive the demand for quality because there are some wonderful hi-end systems available and being sold today. Another important reason for hope within the mass-market is that there is no longer any over-riding reason for MP3 and AAC to have such a following. These formats were designed to overcome very slow download speeds pre-broadband and expensive memory capacity. These are not significant factors for most people now. Even iPods, if loaded with full resolution tracks, can deliver acceptable results through a good system. The trade-off is a smaller selection of stored music. Full resolution audio streaming, as well as CD quality downloads, are already available and will become the norm as the wider public becomes aware of the tremendous quality benefit.



Audiophiles and Hi-Fi Connoisseurs

Hi-fi connoisseurs and audiophiles are very important to the music industry. By their nature, they are generally avid music lovers who enhance their enjoyment through listening to music at its very best quality level, which means playing great recordings through hi-end hi-fi to achieve the most outstanding results. Without them, the main driver for quality would probably be removed from the music industry.

and how to get the best out of it by expert installation in the home. They also appreciate how exciting and involving music can be and how it can deliver a powerful emotional experience. If there's a price premium over an internet purchase by choosing a specialist dealer, it's probably a small one, but it's unquestionably worth the difference.



Specialist Dealers

Specialist hi-fi retailers also come into this category because it's their interest that has driven them into their particular business. These specialist retailers also perform another very important function because, without them, hi-fi manufacturers would have to rely on the internet and hi-fi magazine reviewers to try and assess the relative merits of different brands for potential customers – a notoriously unreliable decision making process. Specialist hi-fi retailers are constantly being offered new products for assessment and potential stocking and, as it is also their hobby as well as their livelihood, they are greatly interested in achieving the best performance and seeking out the most outstanding combinations. More than that though is their relationship with audiophiles and hi-fi connoisseurs for, if they are to stay in business, they must satisfy the most discerning customers in the industry. The reality is that audiophiles and specialist hi-fi retailers (and the ones listed on this page represent the UK's finest) are essential to each other.

Specialist dealers know how to choose the products that combine as a superb system

Listed below is our selection of THE BEST HI-FI DEALERS IN THE UK.

They have been chosen because they are known to do an excellent job in guiding customers towards hi-fi that will give years of musical enjoyment and total satisfaction.

Our Top 20 UK Hi-Fi Dealers

SOUTH

Ashford, Kent
SOUNDCRAFT HI-FI
40 High Street.
t: 01233 624441
www.soundcraft-hifi.co.uk

Chelmsford
RAYLEIGH HI-FI SOUND & VISION
216 Moulsham Street.
t: 01245 265245
www.rayleigh-hifi.co.uk

Kingston-upon-Thames
INFIDELITY
9 High Street,
Hampton Wick.
t: 020 8943 3530
www.infidelity.co.uk

Maidenhead
AUDIO VENUE
36 Queen Street.
t: 01628 633995
www.audiovenue.co.uk

Norwich
MARTINS HI-FI
85-91 Ber Street.
t: 01603 627134
www.martins-hifi.co.uk

Rayleigh
RAYLEIGH HI-FI
44a High Street.
t: 01268 779762
www.rayleigh-hifi.co.uk

Southend-on-Sea
RAYLEIGH HI-FI SOUND & VISION
132/4 London Road.
t: 01702 435255
www.rayleigh-hifi.co.uk

LONDON

Ealing
AUDIO VENUE
27 Bond Street.
t: 020 8567 8703
www.audiovenue.co.uk

N1
GRAHAMS HI-FI
190a New North Road.
t: 020 7226 5500
www.grahams.co.uk

SW11
ORANGES & LEMONS
61/63 Webbs Road.
t: 020 7924 2043
www.oandlhifi.co.uk

SOUTH WEST
Bath
AUDIENCE
14 Broad Street.
t: 01225 333310
www.audience.org.uk

Exeter
GULLIFORD HI-FI
97 Sidwell Street.
t: 01392 491194
www.gullifordhifi.co.uk

MIDLANDS
Banbury
OVERTURE
3 Church Lane.
t: 01295 272158
www.overture.co.uk

Birmingham
MUSIC MATTERS
363 Hagley Road,
Edgbaston.
t: 0121 429 2811
www.musicmatters.co.uk

Coventry
FRANK HARVEY
163 Spon Street.
t: 024 7652 5200
www.frankharvey.co.uk

Leicester
CYMBIOSIS
6 Hotel Street.
t: 0116 262 3754
www.cymbiosis.co.uk

Nottingham
CASTLE SOUND & VISION
48/50 Maid Marian Way.
t: 0115 9584404
www.castlesoundvision.co.uk

NORTH
Cheadle
THE AUDIO WORKS
14 Stockport Road.
t: 0161 428 7887
www.theaudioworks.co.uk

Chester
ACOUSTICA
17 Hoole Road.
t: 01244 344227
www.acoustica.co.uk

Hull
THE AUDIO ROOM
Savile Street, Hull
t: 01482 891375
www.theaudiroom.co.uk

York
SOUND ORGANISATION
2 Gillygate.
t: 01904 627108
www.soundorg.co.uk

These specialist dealers have been selected because they are known to do an excellent job in guiding customers towards hi-fi that will give years of musical enjoyment and total satisfaction.



STAR QUALITIES

VALUE FOR MONEY	★ ★ ★ ★ ★
SERVICE	★ ★ ★ ★ ★
FACILITIES	★ ★ ★ ★ ★
VERDICT	★ ★ ★ ★ ★



ILLUSTRATOR: MAGICTORCH



A material that defies gravity would transform transport, energy and even the weather. **Paul Parsons** examines the latest progress in the experiment that could find it

THE HG WELLS novel *The First Men In The Moon*, published in 1901, saw human beings travel from Earth to our planet's natural satellite in a spacecraft powered by 'cavorite'. This was a fictional antigravity material, capable of blocking the Earth's gravitational pull. For centuries, scientists and philosophers have pondered this problem – how might we counteract gravity, that most fundamental of the forces, which keeps us all stuck firmly to the Earth's surface?

Of course, aircraft and space rockets manage to overcome gravitational pull, but only at considerable cost and effort. True antigravity would allow a vehicle to rise gracefully upwards at the flick of a switch – not just overcoming gravity, but altering its very essence. Now, antigravity

may be about to make the leap from science fiction to science fact. Earlier this year, a team at CERN – the European centre for particle physics, on the border between France and Switzerland – announced plans to look for signs of antigravity in particles of antimatter.

FALLING UPWARDS

Antimatter can be thought of as the opposite of ordinary matter – with all its key properties, like electric charge, reversed. All properties except one, that is. Matter and antimatter both have positive mass, so most physicists had expected them both to behave in the same way when placed in a gravitational field. But now scientists at CERN say this might not be the case after all. They think antimatter might fall at a different rate to ordinary matter – and could even 'fall upwards'.

"Is there such a thing as antigravity? Based on free-fall tests so far, we can't say yes or no," says team member Prof Joel Fajans, of Lawrence Berkeley National Laboratory (LBNL), California. "We certainly expect antimatter to fall down, but just maybe we will be surprised."

Their tests involve an experiment at CERN called ALPHA (short for Antihydrogen Laser Physics Apparatus). The experiment combines antiprotons with antielectrons to make antihydrogen atoms, which are stored briefly in a magnetic field. When the field is switched off, the atoms fall out and move under the action of gravity until they collide with the walls of the apparatus.

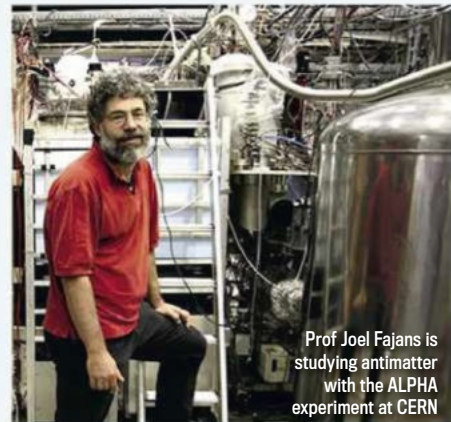
When this happens, a flash of light is given off. By looking at when and where these flashes occur in the ALPHA experiment, the scientists are able to get a handle on how the



➔ antihydrogen atoms are falling in the Earth's gravitational field. Making these measurements, however, is not straightforward. There's much uncertainty owing to the unknown starting positions and speeds of each antihydrogen atom when the magnetic field is switched off. At present, this statistical error is 100 times the size of the expected measurements. "We need to do better," says Prof Jonathan Wurtele, also of LBNL. "We hope to do so in the next few years."

To that end, the equipment at CERN is now being upgraded. When complete in 2014, ALPHA-2 will incorporate a laser cooling system to reduce the energy of antiatoms – so that their speed and position can be more precisely determined. If ALPHA-2 does show matter and antimatter to be falling at different rates, it could be time to rewrite the textbooks on gravity. "That would be new physics," says Dr Michael Doser, of CERN. "While there are not many viable models, a number have been developed which would allow additional gravity-like forces, or modified forms of gravity between matter and antimatter."

While Earth-bound experiments are ongoing, so are searches further from home. Astronomers have found something that most definitely is falling up – galaxies lurking at the edge of our observable Universe. The ordinary matter filling our expanding Universe creates attractive gravity. It was thought this gravity would slow down the cosmic expansion. But when, in the late 1990s, astronomers studied galaxies at different distances from Earth – seen as they were at different cosmic epochs (because of the finite speed of light) – they were in for a surprise. The expansion wasn't slowing down at all, but



Prof Joel Fajans is studying antimatter with the ALPHA experiment at CERN

WHAT IS ANTIMATTER?

The Universe's yin-yang nature

Matter is made of particles such as electrons and protons. But each type of particle has a counterpart with opposite electric charge: antimatter. Antimatter was postulated in 1928 by British physicist Paul Dirac, who had deduced a new theory of the electron. It predicted the existence of positively charged antimatter electrons, now known as positrons. Antimatter was first observed in 1932 and is now regularly made in particle accelerators. When matter meets antimatter the two annihilate, turning their mass into energy. In 1996 scientists put an antiproton and a positron together to make antihydrogen – the world's first antiatom.



The ALPHA-2 experiment is installed at CERN – it will be able to spot any antigravity properties that antimatter might have

A short history of defying gravity

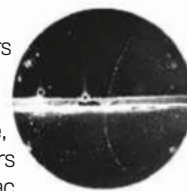
1915 Albert Einstein publishes the General Theory of Relativity (GR), which remains our best description of gravity.



1917 Using GR to build a model of the Universe, Einstein proposes the 'cosmological constant', later known as 'dark energy'.

1921 American physicist Thomas Townsend Brown discovers the 'ionic wind' effect that causes 'lifters' to levitate (see p74).

1932 Carl David Anderson discovers the positron, the first known antimatter particle, predicted four years earlier by Paul Dirac.



1933 Walther Meissner and Robert Ochsenfeld find that superconductors can levitate magnets.

“We certainly expect antimatter to fall down, but just maybe we will be surprised”

Professor Joel Fajans, of Lawrence Berkeley National Laboratory



was actually getting faster. Distant galaxies were accelerating away from us, and the astronomers concluded that some kind of antigravitating material must be responsible.

They called this material ‘dark energy’. It’s actually an old idea. In 1917, shortly after Einstein had formulated his General Theory of Relativity, he used it to build a model of the Universe at large. But his calculations quickly revealed the model to be unstable, recollapsing under its own gravity. To solve the problem, Einstein added dark energy (although it wasn’t called that at the time) to his model – essentially an antigravity-like term in the equations governing his theory. In 1929, when American astronomer Edwin Hubble found that space was expanding, Einstein removed the dark energy term from General Relativity. But by the end of the century, astronomers had found that Einstein’s ‘biggest blunder’ (as he called it) is in fact a real feature of our Universe.

IN THE DARK

In September, UK astronomers announced a new project, called the Dark Energy Survey (DES), to map the distribution of dark energy throughout space – and to chart how this distribution has changed as the Universe evolved. Although dark energy is invisible, astronomers can infer its presence through its anti-gravitational influence on distant galaxies and the light that they emit. Over a period of five years, DES will survey 300 million galaxies in an area covering one-eighth of the night sky.

The study will help scientists better understand the nature and ultimate origin of this curious substance. “We know dark energy exists, but that’s about it. How this substance changes with time and location remains unclear, but we’ll have a better view after DES,” says team member Dr David Bacon, of the University of Portsmouth.

An extreme form of this antigravitating dark energy is believed to have existed shortly after the Big Bang. Called ‘inflation’, it prevented the embryonic Universe from recollapsing back on itself – instead blasting it up from

WHAT WILL WE DO WITH ANTIGRAVITY?

A technological revolution awaits when we finally master this bizarre phenomenon

TRANSPORT



With no need to fight the downward pull of gravity, aircraft will be able to skirt around the Earth at high speed and at a fraction of the cost.

CHEAP ENERGY



Water flowing downhill can generate energy. If you could get the water back to the top of the hill with minimal effort you could generate the same energy all over again.

SPACE FLIGHT



Cosmologist Hermann Bondi showed that if you placed antigravitating matter next to normal matter then the two will ‘self accelerate’. Robert Forward suggested this could be used to build a space drive.

WEAPONS



Antigravity will make it easy to reach orbit. Throw a big rock down from space and it will strike the ground with the force of a nuclear bomb.

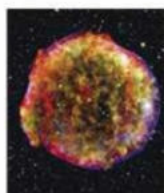
WEATHER CONTROL



Altering gravity would have an effect on atmospheric pressure. This in turn could enable us to control the weather, for example to prevent hurricanes.

1996 Russian Eugene Podkletnov claims to have found evidence for gravity shielding in spinning superconductors.

1999 Supernova explosions provide the first evidence for the existence of dark energy.



2000 The first superconducting maglev train (using the Meissner effect) is successfully tested by scientists in China.

2002 Stories emerge of NASA attempting to reproduce Podkletnov’s work to build antigravity craft.

2013 Physicists at CERN announce details of experiments to discover whether antimatter possesses antigravitating properties.



UP IN THE AIR

The world of antigravity is filled with lofty concepts. Here are some key terms to help you get off the ground



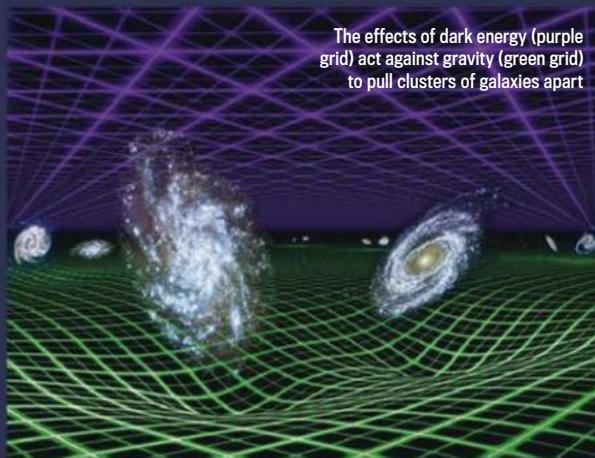
Gravity shielding technology could be used to power flying saucer-like craft

GRAVITY SHIELDING

Russian physicist Eugene Podkletnov claims to have created a device that can partially block the force of gravity. If correct, this would be an example of 'gravity shielding', with the device able to screen out the particles carrying the gravitational force, much like a screen of lead can block particles of radiation like X-rays.

REPULSIVE GRAVITY

The gravitational force between lumps of ordinary matter is always attractive, pulling the objects together. But some forms of matter generate repulsive gravity, whereby the gravitational force pushes objects apart. An example is 'dark energy', which cosmologists believe is causing the expansion of the Universe to accelerate.



The effects of dark energy (purple grid) act against gravity (green grid) to pull clusters of galaxies apart



An artist's impression of a string, which forms the basis of string theory

ALTERNATIVE GRAVITY THEORIES

It may be that Einstein's General Theory of Relativity is not the last word on gravity. Another, deeper physical law may lie beneath, such as string theory. If we find in experiments that antimatter demonstrates antigravitating behaviour then an alternative gravity theory could be the best explanation.

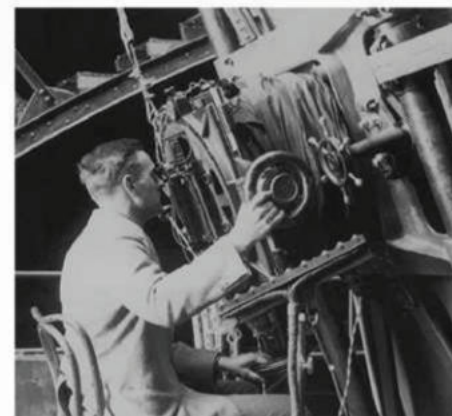
"We know dark energy exists, but how this substance changes with time and location remains unclear"

Dr David Bacon of the University of Portsmouth

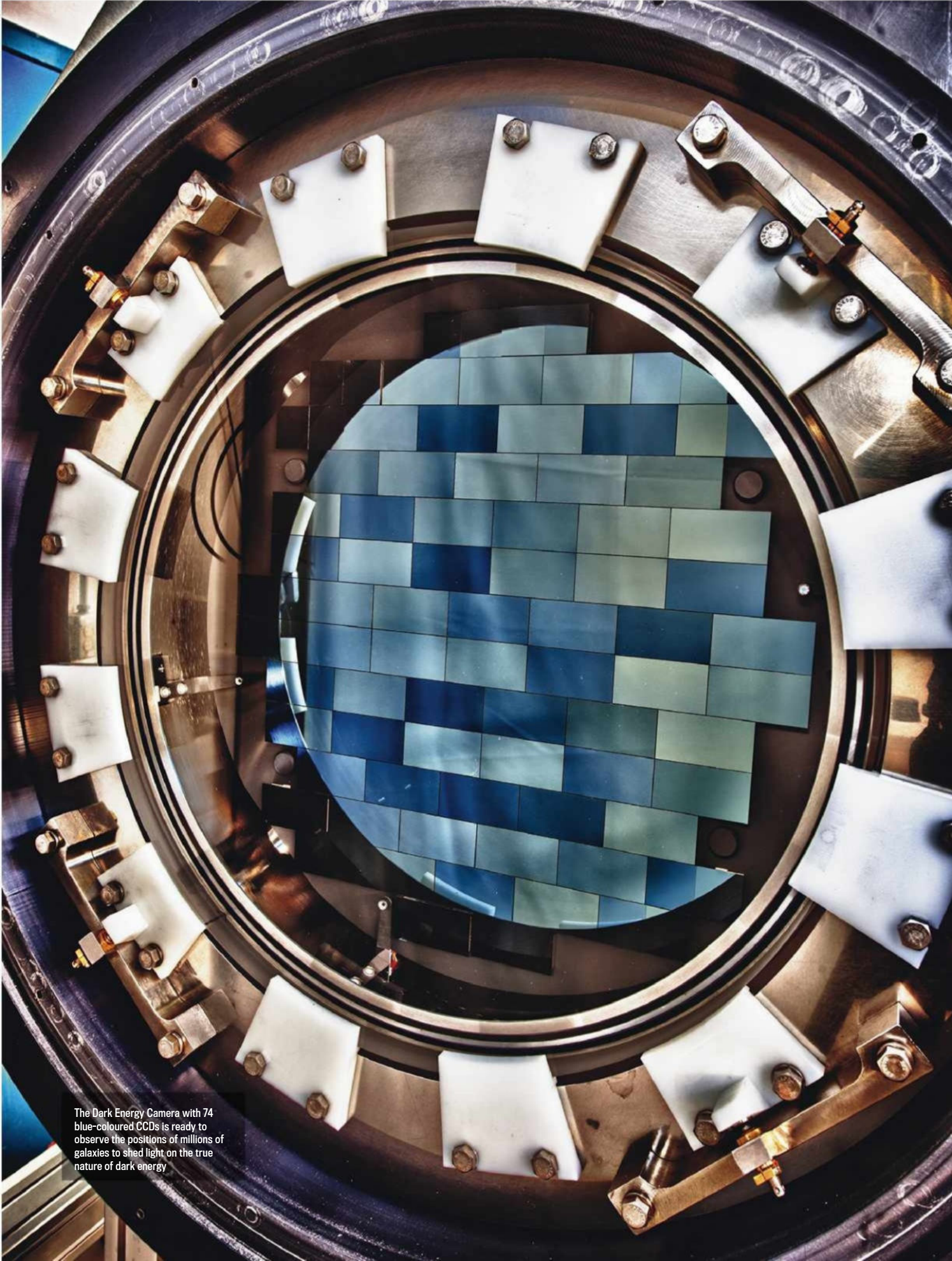
→ microcosm to macrocosm in the tiniest fraction of a second.

Indeed, that we are here at all is at least partially thanks to inflation and dark energy. If the precise amount of dark energy was different, the Universe wouldn't evolve in the same way. "In [models of] universes that have much more dark energy than ours, whenever matter tries to clump into galaxies, the repulsive push of the dark energy is so strong that it blows the clump apart and galaxies don't form. Universes with much less dark energy collapse back on themselves so quickly that, again, galaxies don't form," explains physicist Prof Brian Greene, of Columbia University. "Without galaxies there are no stars, no planets, and no chance for our form of life to exist."

We don't need to look into space to see antigravity in action, however. Experimental physicists have already created small amounts of antigravitating material in the lab, and it has nothing to do with antimatter. In the so-called Casimir effect, named after Dutch physicist Hendrik Casimir who discovered it in 1948, negative energy is created between two metal plates positioned just a few billionths of a metre apart in a vacuum – causing the plates to move together. This happens because empty space



Edwin Hubble discovered that the Universe was expanding



The Dark Energy Camera with 74 blue-coloured CCDs is ready to observe the positions of millions of galaxies to shed light on the true nature of dark energy

➔ isn't really empty at all. It's actually a bubbling mass of virtual particles popping in and out of existence over very short timescales. According to quantum theory – the physics of the subatomic world – particles can equally be thought of as waves. Outside the plates, waves of all possible wavelengths can exist. But between them the waves are rather like vibrating strings – the only vibrations allowed are those for which the length of the string is a whole number of half wavelengths. Converting back to particles, this means that there is less energy between the plates than there is outside. If the outside is a zero-energy vacuum then the inside must have negative energy. And this creates antigravity.

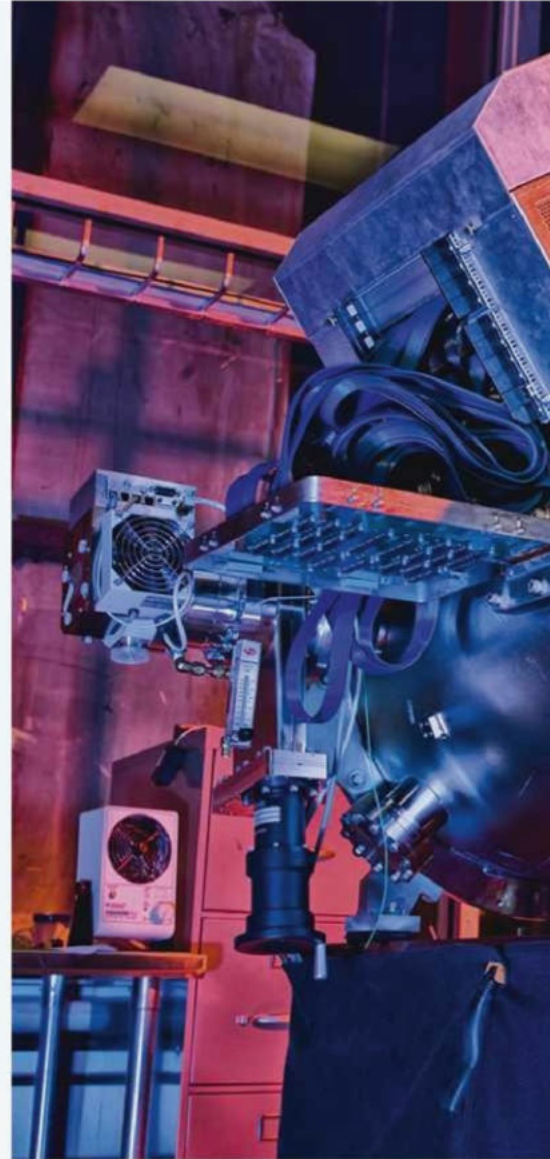
The Casimir effect was verified experimentally in 1997 by Steve Lamoreaux, at Los Alamos National Laboratory. However, the amount of negative mass created was tiny – around -10^{-27} grammes. That's just one ten-millionth (0.0000001) of the force needed to lift a car. In 2009, experimental physicists at Harvard University measured a repulsive analogue of the Casimir effect – which pushes the two plates apart rather than pulling them together. This is possible by varying the materials that the two plates are made from and adding a fluid between them. The 'anti-Casimir effect' can levitate objects, and will be a

“There is important, potentially revolutionary research into the phenomenon of antigravity”

significant breakthrough in nanoscale engineering (where attractive Casimir forces can create unwanted friction between moving parts). However, the anti-Casimir effect has nothing to do with modifying gravity itself and so isn't antigravity in the strictest sense.

Antigravity is one of those fields where amateur scientists frequently feel the urge to contribute. The post bags at *BBC Focus Magazine* regularly bring designs for antigravity machines from inventors, many of whom haven't subjected their creations to adequate testing themselves, let alone the independent scrutiny required to convince a professional scientist.

The place to send an idea for defying the force of gravity isn't a popular science magazine like ours but a scientific journal, whose editors will subject it to rigorous



DEFYING GRAVITY

In the absence of a bona fide antigravity effect, here are three other ways to make things float



Catch a floating train from Pudong airport to Shanghai, China

MAGLEV

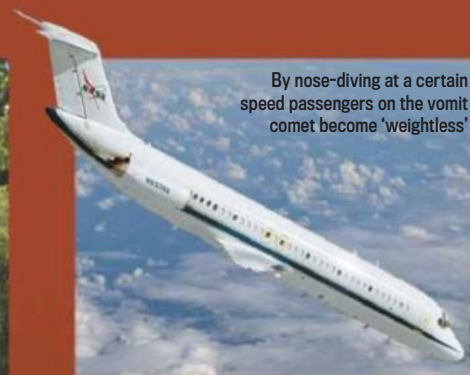
Some high-speed trains forsake wheels in favour of magnets, using the magnetic force to make the train hover above the track, massively reducing friction. As with lifters, this so-called maglev technology isn't true antigravity. The most modern maglev trains use powerful superconducting magnets.



Lifters use a downward wind of charged particles to take off

LIFTERS

Technically these aren't antigravity; they just look like it. A lifter is a triangle of balsa wood covered in tin foil, with a length of thin wire stretched round posts at each vertex. Apply a high voltage (typically 30,000V+) across the foil and the wire creates a downward wind of charged particles, causing the lifter to hover. Don't try this at home!



By nose-diving at a certain speed passengers on the vomit comet become 'weightless'

VOMIT COMET

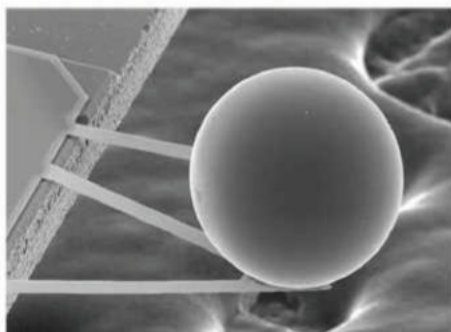
Aircraft such as the NASA 'vomit comet' can reduce the gravity experienced by occupants by nose-diving at a rate equal to the acceleration caused by Earth's gravitational pull. A similar technique is used in 'drop-towers' to create a simulated zero-gravity environment for science experiments.



Scientists put together a prototype of the Dark Energy Camera, which will record the positions of 300,000,000 galaxies

peer review before deciding whether or not it merits publication. One researcher who did just that was Russian physicist Eugene Podkletnov. In a paper accepted for publication in 1996 by the *Journal Of Physics D* (though subsequently withdrawn by its author), Podkletnov reported that objects he placed above a spinning superconducting disc lost 2 per cent of their weight. He was careful to stress that he had accounted for other effects such as air currents and magnetic phenomena.

In an experiment at the University of California, this microscopic ball demonstrates the Casimir effect; the reverse effect can levitate objects



Nevertheless, many regard Podkletnov as either deluded or dishonest. That's because in the 17 years since his paper, no one has been able to replicate his claimed results and not for lack of effort. Teams from international universities and organisations like Boeing, BAE Systems, and even NASA have tried but failed.

"I undertook the first serious attempted replication of Podkletnov's work while I was on the academic staff at Sheffield University," says Clive Woods, now a professor of engineering at Louisiana State University. "We saw no effects ascribable to gravity modification by the spinning superconductor." Prof Woods explains that he was simply unable to recreate the extreme experimental conditions that Podkletnov claims to achieve in his paper. "No one, as far as I know, has managed to reproduce all the required and published conditions and measure a result," he says. "The general conclusion seems to be that it is a wild goose chase." *BBC Focus* emailed Podkletnov for comment. He replied, sending a lengthy and technical electronic book on his work, but declined to tell us whether his research had been independently verified.

ANTIGRAVITY FAQ

Prof Clive Woods of Louisiana State University and Dr Michael Doser of CERN clear up some tricky questions

Would antigravity vehicles need a counterbalancing force to stop them flying off?

"I think it depends on what the hypothetical antigravity system does," say Prof Clive Woods. "If it is antimatter of some sort, then to keep the vehicle on the ground you'd need an opposing force downwards – but then out in space you would need a rocket to give propulsion."

Would antigravitating matter fall up?

Not necessarily. This all comes down to an idea in physics called the 'weak equivalence principle', which says that all objects fall at the same rate in a gravitational field – and which our current understanding of gravity is built on. "This is precisely what our experiment will test," says Dr Michael Doser. "If antimatter were to fall differently from ordinary matter in the Earth's gravitational field, that would be new physics."

Could you use antigravity to propel spacecraft?

Some pretty outlandish-sounding ideas for antigravity spacecraft propulsion have been suggested. "These spacecraft drives alter the space-time fabric in peculiar ways so that the vehicle is constantly 'falling into' a hole, giving propulsion, and if this could be produced and controlled then presumably you wouldn't need a rocket," says Prof Woods.

Yet there is important, potentially revolutionary research into the phenomenon of antigravity. If science can crack and harness the secrets of this perplexing field, they could lead to breakthroughs in transport, energy generation, spaceflight and even weather modification. Ever since the time of Sir Isaac Newton, the laws of physics have insisted that apples fall downwards and not up. Now, that might just be about to change. ■

DR PAUL PARSONS is a former editor of *BBC Focus* and the author of *How To Destroy The Universe* (Quercus, £8.99)

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SUSAN BLACKMORE

Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*



DR ALASTAIR GUNN

Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester



ROBERT MATTHEWS

After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University



GARETH MITCHELL

Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service



LUIS VILLAZON

Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com

or post to *Focus Q&A*, Tower House, Fairfax Street, Bristol, BS1 3BN



A view from the front of Japan's experimental L0 maglev, along with its staggering speed, is displayed on a monitor in front of passengers

Q LIAM CRESSIDY, POOLE

What's the world's fastest train?

A THE FASTEST OPERATIONAL passenger service is China's Shanghai Transrapid maglev line. It hurtles passengers to and from Pudong International Airport at up to 483km/h (300 miles per hour). Maglev trains are propelled by giant magnets in the track and 'levitate' above the track. In a test run, the Transrapid managed 501km/h (311 miles per hour).

However, that record was beaten in August by Central Japan Railway Company's prototype L0 series maglev train. It managed 504 km/h (313mph). Unlike the Transrapid, the L0 is not carrying passengers yet but will eventually service parts of the route between Tokyo and Osaka. Hundreds of kilometres of tunnels need digging and the first section is not due to open until 2027. **GM**

PHOTO: GETTY

In Numbers

1.75 billion

Is the estimated number of years that the Earth will remain habitable. After this the Earth will become too hot for liquid water to exist as it will be too close to a growing Sun.

Q BARBARA HARRIS, POWYS

Do wasps serve any useful purpose?

The red-banded sand wasp drags a paralysed caterpillar away to be a source of food for its offspring



A WASPS ARE ACTUALLY extremely useful. For almost every insect that we regard as a pest there is a species of wasp that has evolved to prey on it. Some wasps simply eat their prey, others parasitise them by laying eggs in their bodies, so that the larvae can hatch and eat them from within. **LV**

Q RON BARNES, KING'S LYNN

Why do black holes shoot out plasma jets?

Polar jets blast out of a supermassive black hole in this artist's impression



A MATTER FLOWING TOWARDS an object naturally forms into a flat, rotating disc called an 'accretion disc'. Astronomers have found that most objects with accretion discs, such as stars in the process of forming, also have 'polar jets'. These are beams of plasma ejected along the rotation axis of the object at its poles. Black holes are found to create the most energetic plasma jets of all, with material rushing outwards at close to the speed of light.

Plasma jets are due to the interaction of an accretion disc with a contorted magnetic field. This interaction results in the acceleration of charged particles away from the object's poles.

How the magnetic field is distorted near a black hole is still not fully understood. One possibility is that the immense gravity of the black hole drags the actual fabric of space-time around with it as it spins. **AG**

Q ALEX LOVELL, BRISTOL

How long can you stand on lava without being burned?

A THE MOLTEN ROCK that spews out of a volcano is still called lava, even after it has cooled down, so it's technically possible to pick lava up in your hand. Pumice stone is a kind of lava, for example. The temperature of lava from an active volcanic eruption varies quite a bit, depending on the chemical composition of the rock.

The fluid 'pahoehoe' lava shown in the photo is mainly basalt and is one of the hottest types. The liquid lava within is at 1,100–1,200°C but the surface crust is a good insulator and will be less than 500°C. The radiant heat would still be enough to scorch unprotected skin and melt the soles of your shoes – a few seconds would be the most you could safely stand on it. The flames on this photographer's shoes and tripod were staged though – they were sprayed with something flammable just before the picture was taken. **LV**



Photographer Kawika Singson said he could only stand the heat for a few seconds

QUESTION OF THE MONTH

If your dog runs away and you live in an earthquake hotspot, it's probably best to run after it!



DAN GRAY, SURREY

How do animals predict natural disasters?

A WE HUMANS DO it by collecting data, inventing theories and building models. Yet we still fail to predict earthquakes, while some other animals seem to have an uncanny ability to escape just before disaster strikes.

In 373 BC, Greek history records that mice, snakes, weasels, centipedes and beetles deserted the city of Helice in the days before a massive earthquake. In 2004 the tsunami that killed 200,000 people apparently killed very few animals.

These stories have sparked much research but no mysterious abilities have been detected. Instead it's likely that animals can sense small foreshocks, unfamiliar vibrations or changes in atmosphere that we cannot. Mice and dogs can hear higher pitched sounds than we can, elephants can hear lower frequencies, and many insects detect vibrations through their legs. So these and other senses might let them detect unfamiliar changes and so escape to safety. **SB**

WINNER!

Congratulations to Dan Gray who wins a copy of *Science Year By Year* (DK, £25)

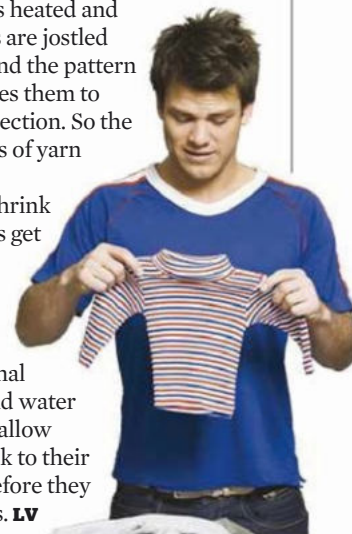


Alice Ley, Wantage

Why do clothes shrink in the wash?

A WOOL IS PRONE to this because animal hairs are made of keratin scales that overlap each other like tiles on a roof. When a jumper is heated and wetted, the fibres are jostled past each other and the pattern of the scales causes them to ratchet in one direction. So the individual strands of yarn tighten up.

Other fabrics shrink because the fibres get stretched during spinning and weaving, and this tension gets locked into the final garment. Heat and water loosen them and allow them to relax back to their original length before they became garments. **LV**



Flora Bell, Cambridge

Why don't some people get motion sickness?

A NO ONE IS entirely immune to motion sickness, but some people are definitely more susceptible than others. Research on twins has shown that if one twin suffers from motion sickness, the other will too and a study at Pennsylvania State University found that 80 per cent of Asians suffered from motion sickness but less than 50 per cent of African-Americans or Caucasian-Americans. So it's probably genetic. It could also be related to your taste sensitivity. People who are more sensitive to bitter compounds are more likely to get motion sickness. **LV**



An in-flight copy of *Focus* would have taken her mind off it

TOP TEN

TOP TEN FASTEST AIRCRAFT

(MANNED AND UNMANNED;
NOT INCLUDING SPACECRAFT)

1. Falcon HTV-2 (unmanned)

Top speed: 20,920km/h
First flight: 2010 (crashed)
Number built: 2

2. X-43A (unmanned)

Top speed: 12,144km/h
First flight: 2004
Number built: 3

3. X-15 (manned)

Top speed: 7,274km/h
First flight: 8 June 1959
Number built: 3

4. X-51 WaveRider (unmanned)

Top Speed: 6,276km/h
First flight: 26 May 2010
Number built: 4

5. SR-71 BlackBird (manned)

Top Speed: 3,540km/h
First flight: 22 December 1964
Number built: 32

6. MiG-25 Foxbat (manned)

Top speed: 3,492km/h
First flight: 6 March 1964
Number built: 1,190

7. Bell X-2 Starbaster (manned)

Top speed: 3,369km/h
First flight: 18 November 1955
Number built: 2

8. XB-70 Valkyrie (manned)

Top speed: 3,308km/h
First flight: 21 September 1964
Number built: 2

9. MiG-31 Foxhound (manned)

Top speed: 2,999km/h
First flight: 16 September 1975
Number built: approx 400

10. F-15 Eagle (manned)

Top speed: 2,679km/h
First flight: 27 July 1972
Number built: 1,198

Q MEL EASTROP, READING

Can an aircraft autopilot fly the entire route?

We could soon be hearing:
"This is your autopilot -
have a pleasant flight"

A THE AUTOPILOT ON an aircraft can fly the whole route apart from take-off. Once airborne, the plane can climb automatically, cruise and then descend all the way to the runway. But 'autoland' is only used when visibility is too poor for a visual approach. Here, three autopilots lock onto the runway's Instrument Landing System (ILS). The ILS is a radio beam coning upward from the ground, forming an invisible tunnel down which the plane flies.

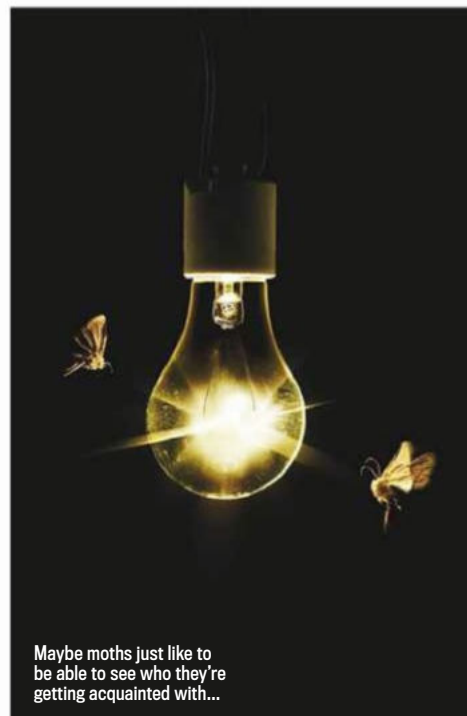
After take-off some flight crew engage the autopilot from about 1,000ft whereas others prefer to fly manually almost all the way to the cruise. After levelling out, the autopilot is usually engaged because otherwise it is hard work keeping a plane straight and level for hours on end. Most autopilots handle turbulence quite well but if it gets really bumpy, the crew might choose to ride it out with the manual flight controls. **GM**

Q PETE RAYNER, HAMPSHIRE

Why do moths fly towards lights?

A MOTHS ARE 'POSITIVELY phototactic' meaning that they move towards light. Some migrating moths use the Moon to navigate and can calibrate their flight paths as it moves across the sky. This is called 'transverse orientation'. So if their instinct is to keep the Moon at a certain angle then mistaking a light bulb for the Moon might easily get them circling around. But many moths don't migrate.

Another theory suggests that female pheromones glow faintly and emit infrared at the same frequency as candles. So male moths might go to their fiery deaths trying to mate with a candle. However, UV also attracts insects more than infrared, and electric light differs from candles, so there is no simple answer to this one. **SB**



Maybe moths just like to be able to see who they're getting acquainted with...

Q J ROBERTS, LIVERPOOL

Is laser propulsion possible?

A USING INTENSE LASER beams as a form of propulsion is possible; in fact, it's being investigated as a means of powering everything from aircraft to small satellites and even interstellar spacecraft. In the 1960s, the pioneering Austrian aerospace engineer Eugen Sänger sketched out the most direct form of laser propulsion: using the blast of radiation pressure from laser light to push vehicles through space. Unfortunately, its simplicity comes at the cost of requiring incredibly intense laser beams that are impractical using current technology. This has led researchers to focus on the more attainable goal of using lasers to blast material off a metal propellant, producing thrust acting in the opposite direction. During the 1970s, experiments in the UK and US suggested this might be capable of launching small payloads into orbit at just one per cent of the cost of using conventional rockets.

So far, however, the only real-life use of lasers in propulsion is for powering



In the future you could take a trip from New York to Tokyo by laser

small drones remotely, where laser beams are used to transmit light energy to photocells on the aircraft. Experiments by NASA scientists in 2002 proved the concept, and it's now being developed for use with small helicopter-like devices. **RM**

WHAT IS THIS?



KNOW THE ANSWER?

Go to sciencefocus.com/qanda/what and submit your answer now!

LAST MONTH'S ANSWER:

Well done to Christopher Hewlett, who correctly guessed hair cells of the inner ear.

Q RAJI LALLI, GRAVESEND

Why is some hair curly and some straight?



The curliness of your hair is governed by the shape of your follicles

A ABOUT 90 PER cent of the difference is down to genes affecting the follicles that produce each hair. Round follicles mean straight hairs while oval or flattened ones produce curly or frizzy hair; some follicles have a hooked end below the scalp and larger hooks mean curlier hair. Tightly curled hair is more common in equatorial regions and straight hair in cooler climates. Perhaps dark curly hair evolved to give better protection from the Sun while fairer straight hair allows more vitamin D production in places with little sunshine. **SB**

Did you know?

The box jellyfish, *Chironex fleckeri*, is the most venomous. Found off north Australia, it produces enough venom to kill 60 humans.



Q RICHARD O'NEILL, GLASGOW

Are there more stars than grains of sand?



If stars outnumber grains of sand, just imagine how many planets there are...

A THE NUMBER OF grains of sand on Earth is estimated to be between 10^{19} (10 quintillion) and 10^{21} (a sextillion). A reasonable estimate of the number of stars in the 'visible' Universe is between 10^{21} and 10^{24} (a septillion). However, the Universe may well be much bigger than just the part we can actually observe, and so could contain many more stars than this. Hence, it seems likely that stars do indeed outnumber grains of sand on Earth. **AG**

Q CAREL LUCAS, PERTH, AUSTRALIA

Why isn't rain salty?

A RAIN COMES FROM water that has evaporated to form clouds. A lot of that evaporation comes from the sea but the salt in seawater can't evaporate.

Salt is mostly sodium chloride (NaCl), which forms crystals where the molecules are held together with strong ionic bonds. These bonds give salt a very high melting point (801°C) and it requires a lot more energy to knock the NaCl molecules into the vapour phase than the water molecules. This means that the salt gets left behind and the clouds are formed of pure water. **LV**



Q MARTIN DUBNER, LONDON

Where does the blood from a bruise go?



A bruise is really a wonderful display of cell reclamation

A A BRUISE occurs when your capillaries break and allow blood to escape into the surrounding tissues. The liquid part of the blood, called plasma, is quickly reabsorbed

by other nearby capillaries and the white blood cells can move in and out of the blood vessels by themselves, but the red blood cells are stranded. Cut off from their supply of nutrients, they initiate a self-destruct sequence, called eryptosis, by changing their cell membranes to attract the attention of white blood cells called macrophages. The macrophages engulf the red blood cells and digest them. The red haemoglobin compound is converted to green biliverdin then yellow bilirubin. These give bruises their characteristic colours, before being released back into the blood stream to be recycled by the liver. **LV**

Q KATIE HEENAN, BY EMAIL

How was energy and mass first created?

A AS EINSTEIN'S FAMOUS equation $E=mc^2$ shows, energy and mass are essentially equivalent, and it's now believed that what we observe as mass – or, more precisely, the sub-atomic particles it's made from – was formed from the energy that triggered the Big Bang. Where that energy came from is, however, one of the outstanding mysteries of science. **RM**

In Numbers

200

is the number of consecutive days that swifts have been found to stay aloft, without stopping for a rest, on their migration route to Africa.

Q RAY CROFT, LEICESTER

What are the coldest star-like bodies?

A THE COLDEST FREE-floating star-like objects known to astronomers are 'brown dwarfs'. But these are really 'failed' stars – they cannot be classed as planets, but do not undergo hydrogen fusion which provides normal stars with their energy source.

The latest research has shown that the coldest brown dwarfs have surface temperatures of between 125°C and 175°C. The boundary between these brown dwarfs and the coolest hydrogen burning stars (red dwarfs) occurs at a mass of about 0.07 times the mass of the Sun. Objects heavier than this are likely to be stars, those below will likely be brown dwarfs.



A brown dwarf is a cross between a planet and a star

However, this boundary is not well defined since other factors, such as the amount of heavy elements in the object, also determine whether or not hydrogen burning occurs. So, although red dwarfs are the coldest 'real' stars, with temperatures as low as 1,800°C, brown dwarfs are the coldest 'star-like' bodies. **AG**

Q EVA CORNELL, BRIGHTON

Should you exercise if you have a cold?

A MOST OF THE time, it makes no difference. Studies conducted in 1998 at Ball State University in the US found that an ordinary head cold had no effect on your ability to exercise. Nor did moderate exercise affect how long it took to recover from a cold. So even though it won't help, you don't need to break your exercise routine just because you have a cold. However, other studies have found that more severe viral infections, such as glandular fever or flu can affect your performance, and pressing on with a vigorous exercise routine can lead to complications or injury. This is because every 1° rise in body temperature increases your heart rate by 1.6bpm and your oxygen consumption by 13 per cent. **LV**



While a cold won't affect your ability to go for a run, we'd still opt for a hot water bottle and cup of tea



Herbal remedy or old wives' tale? If you sting yourself, you'll get to test the dock leaf's soothing abilities

Q CHRIS RUSHTON, BEDFORD

Do dock leaves really heal nettle stings?

A NETTLE STINGS INJECT a cocktail of at least five compounds, including acetylcholine, histamine and formic acid. It's true that dock leaves contain some antihistamine compounds, but I can't find any studies that demonstrate their effectiveness. So in the interest of science, I stung my left arm very thoroughly with nettles from the garden. I left one zone alone as a control, rubbed one zone with fresh dock leaves and rubbed the third zone with grass, to see if it's just green leaves or there's something special about dock.

Rubbing either dock or grass onto the sting produced an initial relief – or at least distraction – but the pain came back as soon as I stopped. After one minute, all three zones were equally painful.

After two minutes, the pain eased a little and bumps appeared on my skin. At four minutes, I had prominent bumps on my arm but the pain was receding fast, and at eight minutes, the pain had virtually gone from the nettles-only patch and was reduced to a warm buzzing feeling in the other two. Then at 17 minutes, the pain began to increase again, peaking at 25 minutes equally in all three zones. It took 24 hours to fade completely, but it disappeared first from the nettles-only zone.

So it looks as if rubbing dock on a sting provides the briefest of distractions but overall makes the sting a little worse. It's probably because you're rubbing the hairs of the stinging nettle deeper into your skin. **LV**

Q TANYA WILLIAMS, CHEPSTOW

Do the phases of the Moon affect your sleep?

A YES. THE POPULAR idea that strange things happen on a full Moon has long been dismissed as fantasy, with many studies since the 1950s finding no connection between the Moon and violence, illness, birth rates or psychotic behaviour. But Swiss researchers recently confined sleepers to a totally dark sleep lab and found that as the full Moon approached, they took about five minutes longer to fall asleep, slept 20 minutes less, and reported their lowest sleep quality on the night of the full Moon. Their levels of melatonin (a hormone that regulates the sleep-wake cycle) and brain activity also changed.

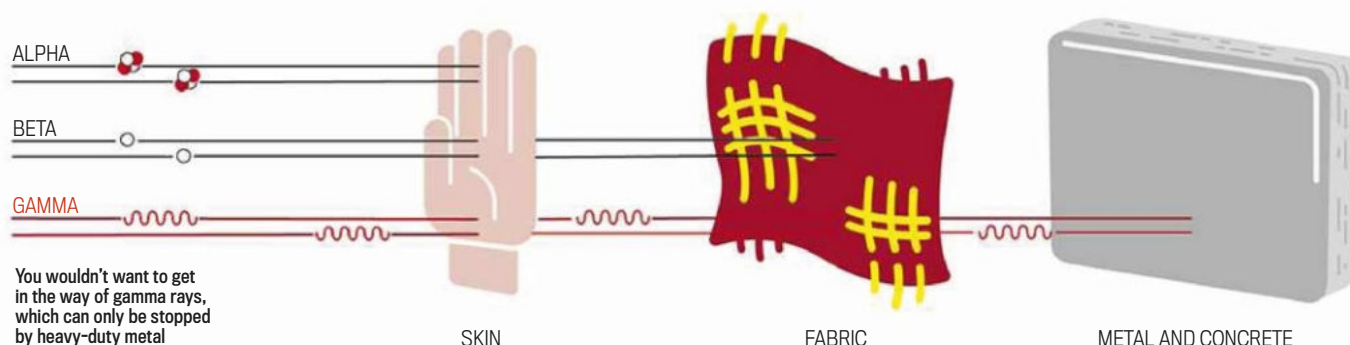
The scientists speculated that humans may, like some other animals, have a built in 'circalunar' (about a Moon) rhythm just as we have a 'circadian' (about a day) rhythm. This might have evolved to give us lighter sleep on bright nights when predators were more of a danger. So, since poor sleep is associated with disturbed behaviours it's possible there's a grain of truth in the old myths after all. **SB**



The phases of the Moon affect some species more than others

Q THEO MATTHEWS, OXFORD

What's the most dangerous form of radiation?



A PHYSICISTS USE THE word radiation to mean any form of electromagnetic radiation, from harmless low frequency radio waves to cancer-causing ultra-violet light and beyond. But what most people mean by radiation is the nasty 'ionising radiation' that packs enough energy to damage living cells. This comes in two forms: particles and

high-frequency electromagnetic radiation. So-called alpha radiation consists of nuclei of helium atoms emitted by radioactive decay of some forms of elements like uranium and radium. It's pretty short-range, and can't penetrate the skin – though some alpha emitters like radon can be inhaled, potentially causing lung cancer. Beta radiation is also

made of particles – high-speed electrons – and packs a bigger punch than alpha particles. It can damage skin, but even ordinary clothes provide some protection.

But most penetrating and dangerous of all is gamma radiation. This can only be blocked by heavy-duty metal and concrete shielding. Depending on dose, it can cause severe burns and death. **RM**

Q ALAN HUGHES-HALLETT, WANSTROW

What percentage of food we eat is useful?

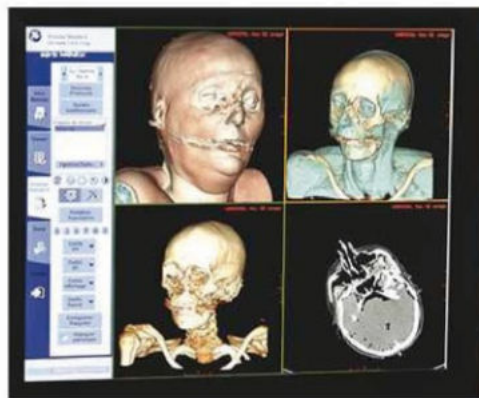
A THERE WAS A 1980 study that measured the food intake of 63 adults from a Cambridgeshire village for a week. On average, they ate 1,277g of food each, per day. Of that, protein, fat and carbohydrate accounted for just 495g. The other 782g isn't useless though. It's mostly water and fibre, both of which are important for the comfortable and efficient passage of the digestible proportion of your food.

If you are trying to lose weight, you could say that anything beyond the calories you need to just run your body every day isn't 'useful', but otherwise virtually all of it contributes in some way. **LV**



Q GRAHAM BARNES, TICEHURST

Are X-ray machines and MRI scanners used to investigate corpses?



MRI scanning is a crucial tool used by forensic scientists to help solve murders

A YES, MEDICAL IMAGING is sometimes used post-mortem. Conventional radiography is the most common technique, but multi-detector computer tomography is also increasingly used. The latter takes multiple cross-sectional slices and is especially useful if a corpse is so badly decomposed or charred that physical examination is difficult. Imaging also works well for tracking gunshot injuries,

by showing up shrapnel or bone along the bullet's trajectory through the body. **GM**

NEXT MONTH Over 20 more of your questions answered



For even more answers to the most puzzling questions, see the Q&A archive at www.sciencefocus.com/qanda



Christmas

❄️ SPECIAL ❄️

p80 What makes stars twinkle? **p81** How tall can a Christmas tree grow? **p81** Why do robins have red breasts? **p84** Why do crackers go bang? **p82** Plus... how to win at board games



How fast would Santa Claus have to fly to visit every child in the world?

A ACCORDING TO Arnold Pompos of Purdue University, Santa would have to travel a total of 160,000,000km – further than the distance from the Earth to the Sun – to visit 200 million children in 800 million homes spread over 3×10^{13} m² of land around the world. He would have about 10 hours, from 8pm to 6am, to deliver the presents. Luckily, children happen to be spread across

a wide range of time zones, buying Santa an additional 24 hours.

Even so, covering this distance in 34 hours is certainly no mean feat. Crunching the figures, we get a speed of 4,705,882km/h, far slower than the speed of light, but still fast enough that the air resistance is likely to vaporise Santa, along with all the children's gifts... if he wasn't riding a magic sleigh.

In Numbers

18,000,000

kilometres is the distance a bus could run on the biofuel generated from processing all of the left-over wrapping paper used in the UK over Christmas.

What makes stars twinkle?



For a festive night-sky sight, use a telescope to see the Christmas Tree Cluster

A EXCLUDING THE SUN, stars are located so far away that even through a telescope they appear as a single point of light. When you look up at a star, turbulence in the atmosphere refracts the light from coming from it in different directions. This makes the star appear to change brightness and position, which can make it look as if it's twinkling.

Is it more environmentally friendly to buy a fake Christmas tree, or a real one?



Banksy's latest piece of guerilla street art failed to garner any interest at all on Boxing Day

A ALTHOUGH THE CARBON footprint of a real tree depends on the method of its disposal, it is invariably lower than that of an artificial tree. According to the Carbon Trust, a 2m tall real tree that ends up in a wood chipper or bonfire has a carbon footprint of 3.5kg of carbon dioxide (CO₂). If the tree ends up as landfill, the footprint increases significantly to 16kg CO₂.

Both of these figures pale in comparison to the carbon footprint of a 2m-tall artificial tree, which is estimated to be 40kg of CO₂. This means you would have to reuse your artificial tree for 12 years to make it greener than a real tree that was burned. If you want to be environmentally friendly this Christmas, your best option would be to buy a potted tree which can be replanted and re-used year after year.



You can marvel at the complexity of the white stuff or simply make a ball out of it and throw it

Is it true that no two snowflakes are exactly the same?

A MOST LIKELY, YES. The science behind snowflake formation is remarkably complex. Scientists are uncertain as to why ice crystals take different shapes at different temperatures, and the influence of humidity is also a grey area. It is believed, however, that the old saying 'no two snowflakes are alike' is true for fully formed snowflakes. It is estimated that there are 10¹⁸ water molecules in a snowflake, and these can arrange themselves in an almost infinite number of ways. Nobody can say for certain that there are no matching pairs, but with odds like that it is probably a safe bet.

Why doesn't a flaming Christmas pudding burn?

A THIS IS BECAUSE it isn't the pudding or the liqueur that is on fire, it is in fact the vapour associated with the alcohol that burns. The flame never actually reaches the pudding itself.

To set a Christmas pudding alight, the liquor must be warmed beforehand; otherwise there will be no vapour to

ignite. Once burning, the heat generated warms the liquid alcohol in the pudding, creating more vapour until eventually there is no more alcohol left to vapourise. At this point, the flame burns out and the pudding is left tasty and un-charred. And you hopefully won't have burnt the house down.

Christmas pudding
luckily never
tastes burnt since
the flame never
touches it



Why does Santa have a beard but not Mrs Claus?

A MEN GROW FACIAL hair because of the stimulatory effects of male hormones like testosterone. Professor Paul Sherman of Cornell University believes that it is likely that a beard's colour and texture played a role in 'sexual selection', meaning beards were useful for attracting mates or intimidating rivals. A beard could cushion a man's face against blows in a fight and hide scars from previous fights.



Santa wouldn't be as attractive without his beard

How tall can a Christmas tree grow?

A THERE ARE VARIOUS different species of tree that are typically used as Christmas trees, including spruces, firs and pines. The maximum height depends on a number of factors such as where the tree is grown and the growing conditions, but primarily on the species. There are reports of Christmas trees exceeding 100m in height, but in recent years, the tallest Christmas tree recorded was a Douglas Fir that was a staggering 62m in 2005. The species can grow to 75m in height.

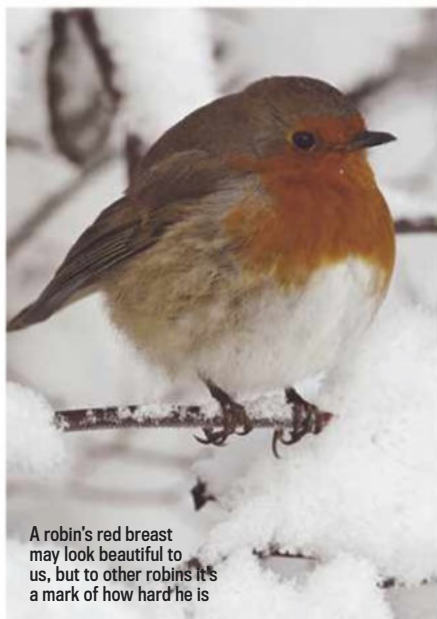


Stockholm takes Christmas trees very seriously

Why do robins have red breasts?

A THE ROBIN'S DISTINCTIVE red breast is a beautiful sight as it's seen against a backdrop of fresh snow. It's actually a tool in their ongoing campaign to gain or retain territory, according to research from the University of Cambridge. For each year that passes, a male's red breast gets a little larger.

Robins do not typically die of old age, so every year a robin survives is a credit to its survival skills. Following this logic, an older robin with a large red breast is a real threat, as his survival skills must be very well honed. Such a robin could therefore use his breast to attract mates, or to intimidate younger birds in battles over territory.



A robin's red breast may look beautiful to us, but to other robins it's a mark of how hard he is

HOW CAN I WIN AT CHR

WORDS: ADAM KUCHARSKI

MONOPOLY Dominate with savvy business moves

THE AIM OF Monopoly is to own so much of the board that it drives your opponents into bankruptcy. But which colour squares should you buy? One way to assess a square's value is to calculate its 'return on investment': how much rent you can charge compared with how much you bought it for. If we look at rent versus price, the light blue squares generate the highest returns when your opponents land on them. But how likely is it someone will land on a particular square?

We can work out which squares a player might visit by calculating the probability of a certain dice throw. Suppose you are currently on the 'Go' square. With two dice, you'll only move two spaces if you roll a pair of ones. There's a $1/6 \times 1/6 = 1/36$ probability this will happen. Moving three spaces is twice as likely: you could get a '1' on the first die and a '2' on the second, or vice versa. This translates into a probability of $2/36$. We could tally up the probabilities of getting each number, and work out where people might land after several rounds of play. Unfortunately, this becomes a bit tricky because if you land on the 'Go to Jail' square, you skip half the board.

Rather than trying to calculate a hefty set of probabilities, we can instead use

a computer to simulate lots of games and see what happens. This is what computer scientist Truman Collins did in 1997. Taking into account where people might land, he found that it's generally best to buy property on orange squares.

It's worth remembering that this is only the best strategy on average: the game will occasionally end differently. In fact, the game might not come to an end at all. In 2009, researchers at Cornell University wrote a paper titled 'Estimating the probability that the game of Monopoly never ends'. With two computer players, the team found that about 12 per cent of games went on indefinitely. Luckily, there are some ways to ensure that the game doesn't take all Christmas to finish. In particular, try limiting the supply of money. Don't hand out a bonus when someone lands on 'Free Parking', and don't allow players to borrow or lend cash.



CHRISTMAS BOARD GAMES?

MONOPOLY TIPS

ONE



Early in the game, get out of jail as soon as possible so you can keep buying properties. Later on, it's worth staying in jail to avoid paying rent, especially if your opponents own lots of squares.

TWO



Buy properties in the half of the board between 'Jail' and 'Go to jail'. Your opponents will land on these squares more often than others.

THREE



If you own a property, build three houses on it. The profit you can expect to make from building doesn't increase evenly with every house: once you hit the magic number three, the pay-off suddenly becomes much larger.

CONNECT FOUR

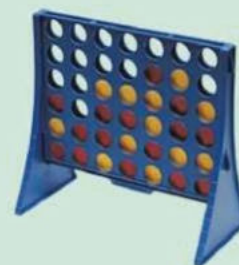
A few clever techniques will help you come out on top

GAMES LIKE CONNECT Four are less complicated than Monopoly, which means it's possible to work out who would win if both players make no mistakes. James Allen found such a 'solution' to Connect Four in 1988. Whereas a perfectly played game of noughts and crosses will always end in a draw, Allen showed that the player who goes first in Connect Four can always win.

You probably won't want to spend ages memorising the entire strategy, but there are a few tactics that could tip the game in your favour. Of the seven vertical slots on the Connect Four board, you should try and control the middle one, as there are more ways to get four-in-a-row – and hence win – if you have counters there.

It's also important to steer your opponent towards positions that help you. You can do this with tactically placed three-in-a-rows, as your opponent will have no choice but to place a counter in a position that stops you getting four. This is especially useful for regaining the upper hand if you have to start second.

Plan multiple threats too: if you can create two sets of three-in-a-row at the same time, you will win on your next go.



SCRABBLE

It's not all about trying to place the longest word possible...

UNLIKE CONNECT FOUR, nobody has found the perfect strategy for Scrabble. But researchers at the University of Illinois have gleaned some insights using computer simulations. Although a good vocabulary is important, managing the seven letters on your rack is vital too. Rather than always playing the best word possible, you should try and ensure you keep a good mix of vowels and consonants, and avoid duplicate letters.

It's also worth trying to predict what tiles your opponent might have, based on what's already been placed on the board. In a simulated two-person game, the Illinois team found a player who knew their opponent's exact letters won 40 per

cent more games. Even without such good information, the researchers recommend trying to spot when your opponent can use all their letters (and pick up a huge bonus).

Luck plays a large role in Scrabble. While one set of bad cards might not hinder you in poker, a weak set of letters at the start of a Scrabble game can ruin your chances.



Why do crackers go bang?



Crackers: the only time you can have family fun with gunpowder in the home

A INSIDE A CRACKER there are two strips of card, attached end-to-end with a slight overlap. This overlap is treated with gunpowder – a mixture of potassium nitrate, charcoal and sulphur. When the cracker is pulled, the friction generated between the two strips causes enough heat to set the gunpowder off. The tube amplifies the sound of the tiny explosion.

Why do we find it harder to get to sleep when we're excited?

A BEING EXCITED MAKES you think about the next day and imagine different scenarios. That requires some concentration, which keeps you awake.

As you lie there, tired but not sleepy, you may start to imagine how exhausted you'll feel the next day if you don't get enough sleep. So now you're thinking about your own insomnia, and the more you focus on it, the more your mind races and the less sleepy you feel. Stress, worry and excitement also cause your body to produce adrenaline and cortisol, which raise your heartbeat and make you even more wide awake.

In Numbers

379,090,650,000

is the predicted number of calories that will be consumed in the UK on Christmas Day. Per person, it equates to almost double the daily typical intake.

What are the chances of a white Christmas?



The stage was set for Wham!'s re-release of 'Last Christmas'

A THIS REALLY DEPENDS on your definition of a white Christmas. If you're hoping for the classic Christmas card scene of a blanket of snow lining your garden, then you will more than likely be disappointed: according to the Met Office there has only

been a widespread covering of snow on Christmas Day four times in the last 51 years. For those who are a little less fussy, there is a much higher chance of at least one snowflake falling on Christmas Day: this has happened 38 times in the last 51 years.

Why do some people hate Brussels sprouts?

A SURPRISINGLY, IT COULD be your genes that determine your feelings about these controversial little vegetables. A 2011 study by Cornwall College found that sprouts contain a chemical, similar to Phenylthiocarbamide, which only tastes bitter to people who have a variation of a certain gene. The research found that around 50 per cent of the world's population have a mutation on this gene. The lucky half don't taste the bitterness usually associated with sprouts, and therefore like them a whole lot more than everyone else.



If you liked *Snakes On A Plane* you'll love *Sprouts On A Fork*

Does being heavier make you go faster on a sledge?



Put on the pounds over Christmas and you'll be able to go that little bit faster on a sledge... every cloud

A THERE ARE A number of variables at play when it comes to the speed of a sledge, and weight is certainly an important one. Assuming there is a reasonable amount of snow on the ground, heavier people tend to go faster as they can cut through the snow on top

to make contact with the fast, slippery ice underneath. The size that comes with additional weight is likely to slow you down, as it will make you less aerodynamic, but this will only have a pronounced effect at high speeds in very icy conditions. Interestingly, during luge

sledding, where such conditions exist, heavier sliders go faster at the top of the track and slimmer, more aerodynamic sliders go faster at the bottom of the track. This is due to improved aerodynamics, according to Mark Hatton, who represents the luge sledding Olympic GB team.



And you thought Christmas presents couldn't get any worse than a garish jumper

Are humans the only animals that give gifts?

A WE CERTAINLY ARE not alone in our gift-giving ways: many other species exchange gifts, and often with exactly the same motives as us. Researchers at Brock University in Ontario found one such example. They reported that in many species of bird, the male attempts to charm his potential mate by presenting her with an assortment of edible gifts during their courtship.

A somewhat more altruistic form of gift giving was exhibited in an experiment at Duke University, North Carolina. Researchers led a bonobo ape into a room with an array of food inside. Rather than keeping the food to itself, the bonobo consistently unlocked a nearby door and shared the food with an unacquainted bonobo.

Animals that give gifts outside their species are far less common, but you don't need to look far to find an example. Domesticated cats that bring their deceased prey into the home are actually being quite sweet: having twigged that you are pretty rubbish at hunting for yourself, they decide to help you out and do the job for you.

DO YOU KNOW ANY GOOD CRACKER JOKES?

We asked our followers on Facebook and Twitter for funny lines to use on Christmas Day

A photon checks into a hotel and is asked if he needs any help with his luggage. "No thanks, I'm travelling light."

@CHRISAAAAYYY

I was going to tell you all about the history of Denmark's contribution to physics but I realised that would just be a Bohr.

@alex_brown

There are 10 types of people. Those who understand ternary, those who don't, and those who thought this joke was about binary.

@picklewalsh

Q. Why did the chicken cross the Möbius strip?

A. To get to the same side!

@BritaBevis

Q. Why do chemists like nitrates so much?

A. They're cheaper than day rates!

@Gerbera4U

"Never trust an atom - they make up everything."

@beedle82

"I ruined my Airfix kit of the Large Hadron Collider. I put too much gluon"

@stevessplan

Q. Why did the mutually exclusive events break up?

A. Because they had nothing in common.

@MathsForMasses

Higgs Boson goes to the Vatican. The Pope says "What are you doing here Higgs?" Higgs replies "You can't have mass without me."

@picklewalsh

Q. How many astronomers does it take to change a light bulb?

A. None, they use standard candles.

@MikeStewart75

Q. What would happen if Iron Man and the Silver Surfer teamed up?

A. They would become alloys

@picklewalsh

One Hydrogen says to another, "I think I've lost an Electron". The other says, "are you sure?". It replies, "I'm positivel"

@Bri_Wallace

I was going to make a joke about sodium hydride, but... Nah.

Geat

Someone once threw sodium chloride at me... That's a salt.

Austin O'Meara

A neutrino walked through a bar...

Andrew Rubotham

Schrödinger's Cat walked into a bar, maybe.

@MathewTweet

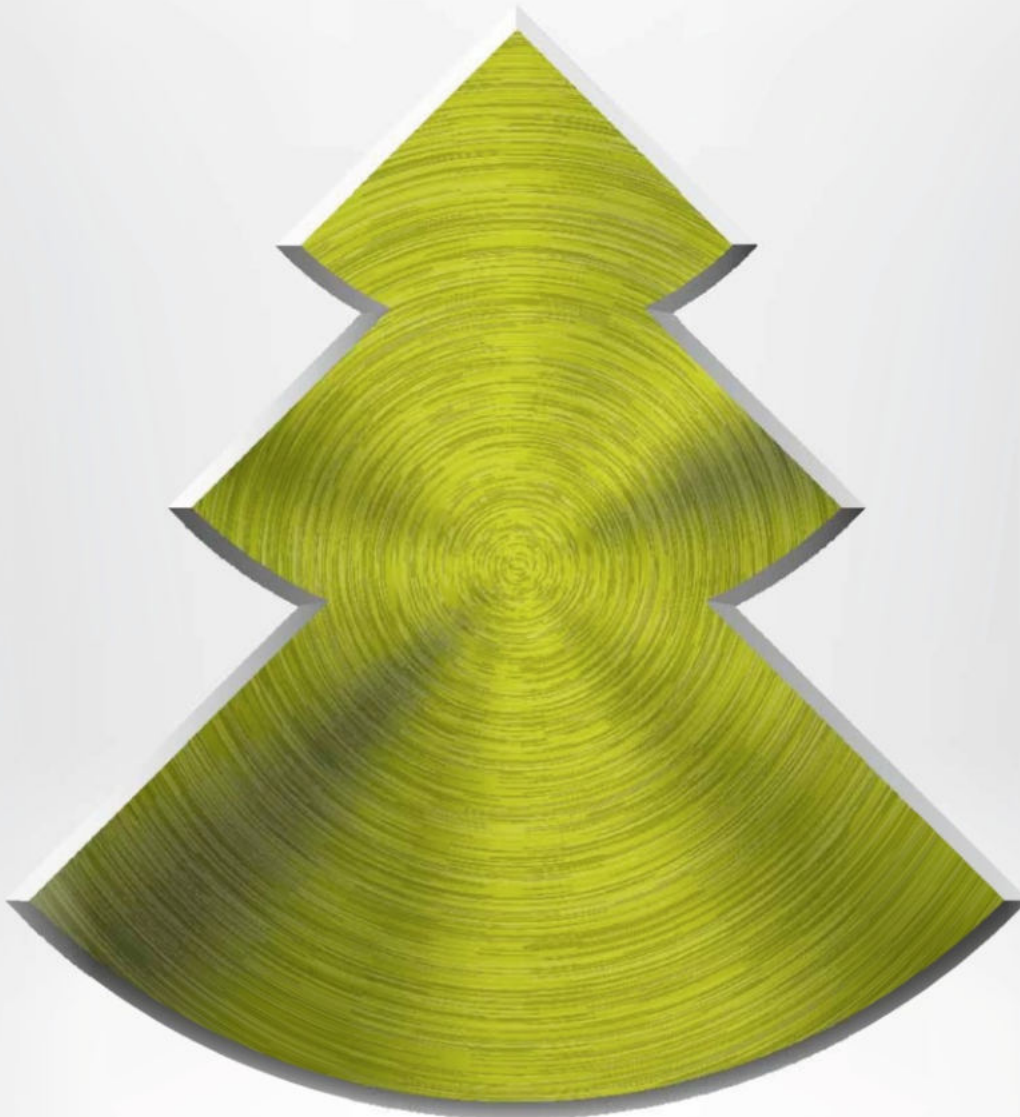


GOT A JOKE?

Send us more funny gags at twitter.com/sciencefocus using the hashtag #sciencejokes

CHRISTMAS GIFT GUIDE

WHAT TO GET THE TECH LOVER IN YOUR LIFE



ICONIC PRODUCTS TO INSPIRE THE
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audio settings to suit your music, mood or surroundings. Zik comes in four colours, with a travel-friendly carry case and spare battery also available.

Stockist – Amazon, Apple Store

design by **S+ARCK**[®]



Audio-Technica

THE BRAND NEW ATH-ANC70 QUIETPOINT HEADPHONES from Audio-Technica provide up to 90% noise cancellation and offer a host of features including a mic and controller for answering calls and controlling your music, completely integrated electronics with all functionality built into the earcup, and a new comfort-fit design.

Designed to provide total long-wearing comfort, the earpads and headband are made from memory foam making them incredibly soft and comfortable to wear.

The ATH-ANC70 will be available from November 2013 directly from Audio-Technica's online store www.audiotechnicashop.com, Amazon as well as many good electrical and headphone retailers at a recommended retail price of £149.00.

 **audio-technica**



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RATstands



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Prices start at £20 for iPhone cases, to £145 for large rucksacks.





Joby

JOBY revolutionised the camera accessories market in early 2006 with its GorillaPod line of flexible tripods and continues to develop awesome photography-related products like GripTight for smartphones and the UltraFit camera strap. We believe that great design starts with a user-centric approach, is functional yet playful, and enhances people's lives.

JOBY GORILLAPOD ORIGINAL

Featuring over two dozen flexible leg joints that bend and rotate, the Joby GorillaPod Original will firmly secure your compact camera to virtually any surface, allowing you to get in the picture and become part of the memories. The slim-line quick-release clip stays connected to your camera and snaps into the GorillaPod for instant setup. Retailers for around £20. www.joby.com

JOBY GORILLAPOD HYBRID

The GorillaPod Hybrid features flexible, wrappable legs for hands-free shots and rock-solid stabilisation on most surfaces. The integrated ball head with 90° tilt and 360° pan helps you capture professional images without the hassle of a full-sized tripod. Holds up to 1kg but alternative sizes are available. Retailers for around £35. www.joby.com

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The Joby UltraFit Sling Strap™ is optimised for on-the-go photographers with Layered Pad Technology™ that evenly distributes the weight of the camera without the bulk of thick padding. The integrated SpeedCinch™ system secures the camera close to the body for extra mobility and camera protection, but in one fluid movement extends from cinched to shooting meaning you never miss that perfect shot!

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JOBY GRIPTIGHT MOUNT

Smartphones with awesome cameras come in all shapes and sizes, but to maximise the quality you really need to use a tripod. The Joby GripTight Mount attaches to any tripod via a standard screw thread and adapts in size to fit most smartphones. The mount alone retails for around £13 and also comes available as a kit with either a GorillaPod or Micro stand at approximately £25 each.

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Anymode is the leading provider of the mobile accessories market in Asia, considered the best brand for sophisticated mobile style, fashion and high-end technical appliances. Anymode was most recently awarded the "Best Design Brand 2013/2014" in the telecommunication segment by the Plus-X-Design Award Jury.

ME-IN FOLIO COVER FOR SAMSUNG NOTE 3

This case has an integrated mirror. The front cover is made of fine, mirrored glass and the back case is high-quality leather.

Feminine and practical, it enables you to check your make-up any time, any place. And there's another integrated special effect: when you receive a call, your screen shimmers through the phone as if through a magic mirror, which allows you to see the device display.

The touch-sensitive cover enables your fingers (this feature is only available for the Note 3 Me-In Cover) as well as the integrated stylus pen to work on the glass so you can keep the cover closed while using it. The back case is high-quality leather and is available in black, dark-blue, red and orange. The Me-In is also available for the Samsung Galaxy S3, S4 and Note 2.

FOLIO FRAME CASE

This unique casing, that is a perfect and eye-catching fit for the iPhone 5 and iPhone 5s, will always have you feeling on top form. The stylish case fits the new smartphone like a second skin, and the peerless craftsmanship will turn heads!

The high-quality finish bears the unmistakable hallmark of Anymode exclusivity, while providing all-round protection for your phone. An integrated magnet ensures that the frame case can be fully closed to maintain a tight fit around the smartphone so it never loses its sleek line.

FOLIO HARBACK STAND

This case has the look and feel of genuine leather but is made of Polyurethane.

The battery replacement cover makes sure that your Galaxy Note 3 keeps its ultra slim design and, with the speaker hole on the front, you can use your phone while the cover is closed.

The integrated stand function for hands-free viewing of videos is useful in your everyday life. Available in black, white, brown and beige.



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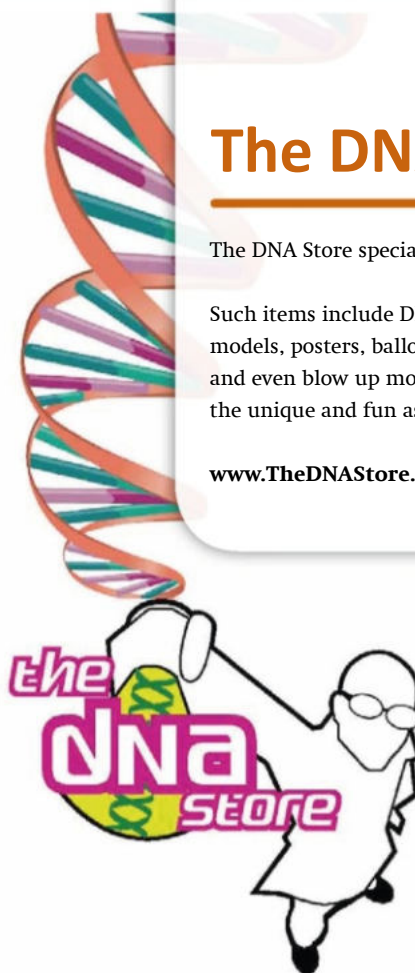


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Stockist – Amazon

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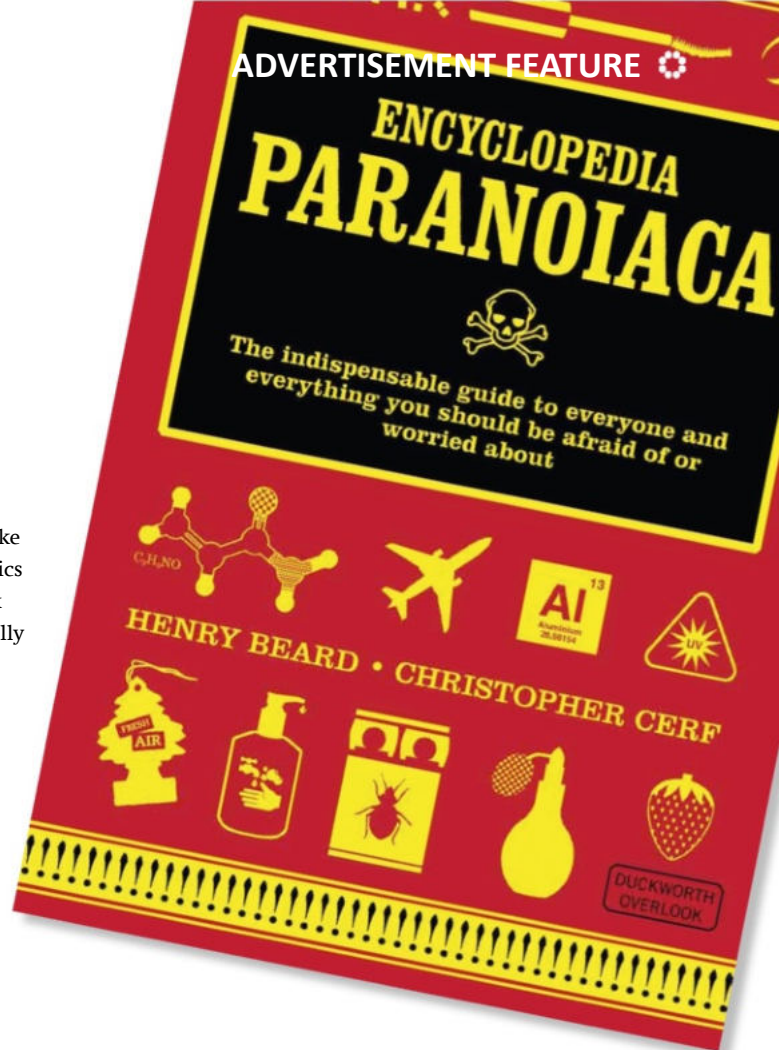
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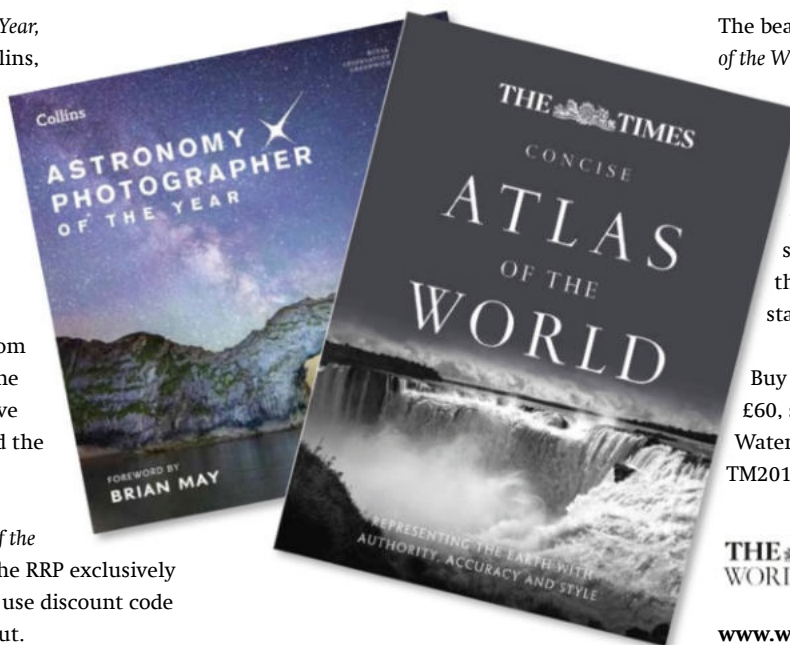


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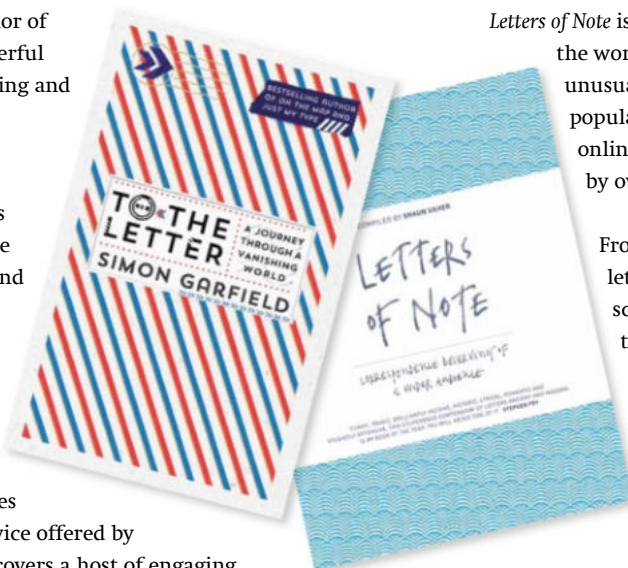
A celebration of letters and how they've shaped our lives

From Simon Garfield, the bestselling author of *On the Map* and *Just my Type*, comes a wonderful journey through the history of letter-writing and our relationship with the mail.

From Roman wood chips discovered near Hadrian's Wall to the wonders and terrors of email, *To the Letter* explores how we have written to each other over the centuries and what our letters reveal about our lives.

Along the way he delves into the great correspondences of our time, from Cicero and Petrarch to Jane Austen and Ted Hughes (and John Keats, Virginia Woolf, Jack Kerouac, Anaïs Nin and Charles Schulz), and traces the very particular advice offered by bestselling letter-writing manuals. He uncovers a host of engaging stories, including the tricky history of the opening greeting, the ideal ingredients for invisible ink, and the sad saga of the dead letter office. As the book unfolds, so does the story of a moving wartime correspondence that shows how letters can change the course of life.

To the Letter is a wonderful celebration of letters in every form, and a passionate rallying cry to keep writing.



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Letters of Note is a celebration of the power of written correspondence which captures the humour, seriousness, sadness and brilliance that make up all of our lives.

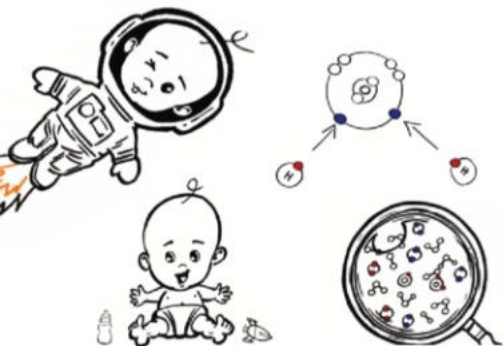
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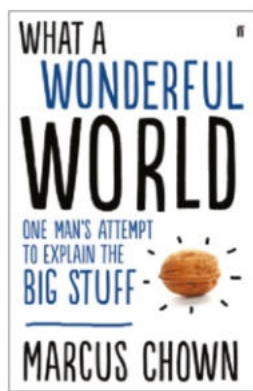
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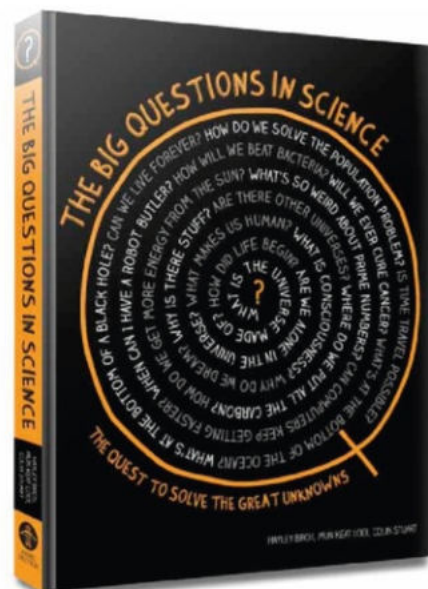


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ON THE HORIZON

NEST PROTECT

THE SMART SMOKE ALARM

WORDS: **SAM KIELDSEN**

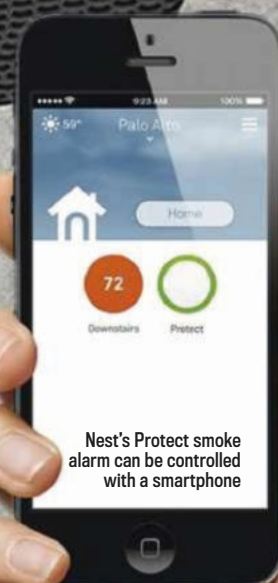
Nest.com, \$129
(£80 plus P&P)

MOST smoke alarms are awful. The merest whiff of burnt toast can trigger their ear-piercing cry. When they run out of battery they let you know with a persistent beep, which can drive some home owners to turn them off altogether.

We've accepted these frustrations for so long because smoke alarms keep us and our loved ones safe. But a new device promises a more

advanced and controllable way to guard against house fires. The Nest Protect is a smoke and carbon monoxide alarm with a difference – it's smart. If a fire does break out, it will tell you precisely where it is and what you need to do. What's more, thanks to built-in Wi-Fi, it's controllable from your smartphone or computer.

The unit itself has an easy-to-read LED light. At a glance you can see if everything's okay (green), if the battery's running low (yellow) or if the alarm is sounding (red). The





A green light on Nest Protect means your home isn't burning, but watch out when you're cooking fry-ups

→ rest of the time you'll control it from your phone. Remote wireless access lets you keep tabs on its battery life – you'll get a notification when it's running low, so there's no need to get the stepladder out once a month. It also allows multiple Protect alarms to work together. If you have detectors in several rooms, they'll communicate with each other so that you'll know exactly where the smoke is coming from. It'll even bring up a quick-dial button to call the fire brigade.

Communication, in fact, is one of the ways the Nest Protect leaves current smoke alarms – most of which do little besides beep – in the dust. It issues spoken warnings, so if your cooking causes enough smoke to trigger an alarm, you'll have the chance to silence it (via a wave of your hand) before the alarm starts to sound. There's also a human voice alarm designed to wake up young children in the event of danger. Studies have found that children tend to sleep through beeping alarms but will react quickly when they hear a human voice – particularly a mother-like female, so the Protect offers suitable female accents for every region in which it's sold. As well as talking to the kids, the Protect will work

with other Nest devices, such as the Nest Thermostat, turning off the boiler if it notices a dramatic rise in carbon dioxide, for example. It's possible it could speak to other devices in the home in future too.

Nest Protect aims to come top of the pile in terms of safety by offering more than any other smoke detector. The device packs a suite of sensors able to pick up various types of smoke as well as carbon monoxide and carbon dioxide. It can also detect moisture, light and motion.

And there's a nice bonus on board, too: Pathlight. This feature uses the Protect's motion sensor to detect when someone is walking nearby at night. As you pass, the Protect's LED glows to light up your hallway, landing or living room, ensuring you don't stumble over your kids' toys on the way to the bathroom.

It's set to go on sale next year and with so much technology crammed into a sleek, stylish box, the Nest Protect is likely to leave your current smoke detector seeming a little crude by comparison.

SAM KIELDTSEN is a freelance technology journalist based in New York

TECHOMETER

WHAT'S HOT

CURVED PHONES

Samsung and LG have both announced curved smartphones. While the phones won't change the world, the flexible screens needed to make them might. Their malleability makes them impossible to smash and, as more manufacturers use OLED screens, the price of producing them will fall, opening up the market for other companies to use flexible screen technology more imaginatively.



WHAT'S NOT

SNAPCHAT

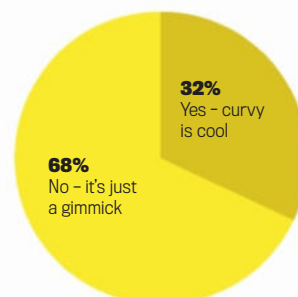
It seems the go-to app for sharing messages, pictures and videos securely isn't as safe as its users think. Normally Snapchat "destroys" any message or file seconds after it's received. But a developer, looking to demonstrate the frailty of such services, managed to create an

app called Snaphack that intercepts messages and images sent via Snapchat and save or pass them on.



READER POLL

Will you buy a curved phone?



THE NEXT BIG THING

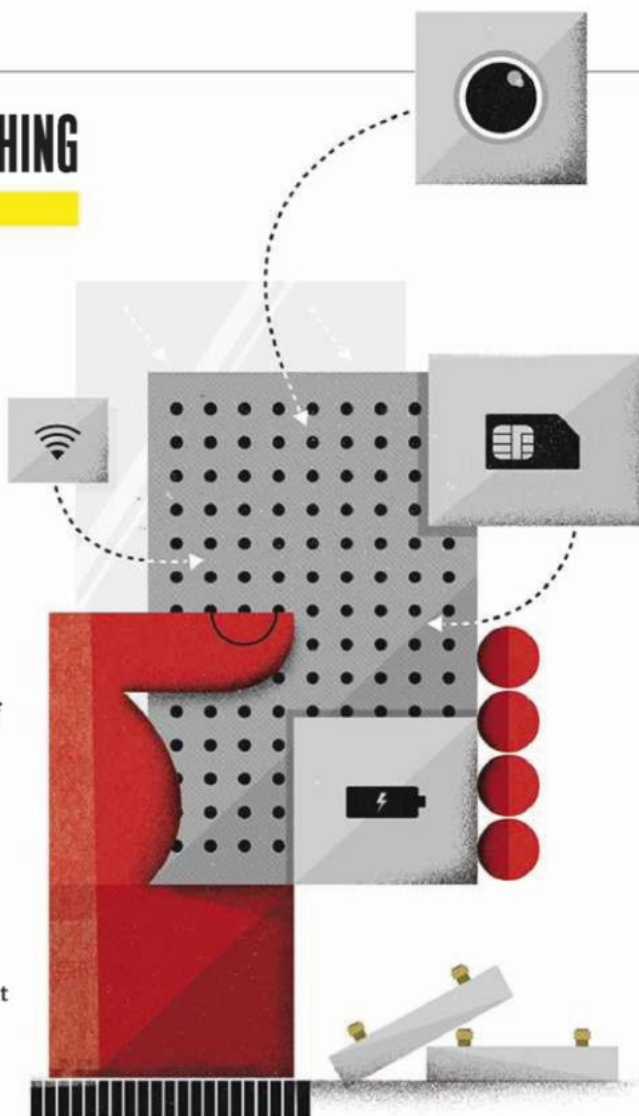
MODULAR PHONES

Stansted airport, 1991. That was where I was when I made my first mobile phone call. A few years later I was regularly using a Motorola TAC and, since then, I doubt I've gone more than a couple of days without a cellphone.

In the last 20 years phones have got smaller and smaller, then bigger, more powerful and more flexible. Each advance – whether it's been better battery life, a camera or a touchscreen – has seduced me to buy a new device. But a new proposal by Dutch designer Dave Hakkens could take things a lot further by giving us modular phones that snap together like Lego. This lets you upgrade some of its components without having to ditch a whole phone, which is surely a boon for the environment.

Phonebloks is a simple idea, even if the execution could be fiendishly complex. Instead of having a phone as a sealed unit, you start with a rectangular baseplate and attach a screen and/or keyboard to one side and a collection of phone-based components to the other.

The resulting phone is reconfigurable, so if you want a better camera you can snap your existing one out and replace it; or swap the storage block for a bigger battery. It would also allow you to replace a broken part without having to get a whole new phone, a



boon to anyone who has ever cracked a screen.

But while it sounds like a great solution to a growing problem, there are many obstacles to overcome before we see anything like a modular phone. Phone manufacturers would have to collaborate on a shared platform that none of them would own or dominate, something that would be difficult and might even fall foul of laws intended to stop anti-competitive agreements.

But the real problem might be the physics of electronic systems. One reason the components in a phone are so tightly packed is so they can communicate quickly to make the device responsive. The way a Phonebloks phone works would make that hard to

replicate, so even if you could build one it might be sluggish. One solution would be to replace the electronics with optical channels, but that's still some way off. For the moment, the snap-phone looks like an inspirational idea that might not come to fruition any time soon.

In the meantime, I can already improve battery life on my phone by adding an external battery, or improve the camera quality with a Sony QX10 or QX100 'smart lens'. So in some ways modularity of some sort is already quite achievable.



BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service

COMING SOON

3 MONTHS

ADIDAS FITNESS TRACKER

The sportswear company is releasing a smartwatch soon that's geared for runners. Not only will it track your route, speed and distance but it'll also offer on-the-fly coaching advice. Adidas.com



+ Samsung Ativ Q

This tablet will be able to switch between Android and Windows operating systems, giving you the best of both worlds. Samsung.com

+ Sony SmartWatch 2

This smartwatch will work with any Android-powered device, comes with a larger screen and will offer advanced features. Sony.com

6 MONTHS

VALVE STEAM BOX + REMOTE

The company behind the most popular online games shop in the world, Steam, is now taking on consoles. Although it hasn't revealed the hardware, it has unveiled the controller, which uses touch-sensitive trackpads. Valvesoftware.com



+ Haier Eye Control

Ditch the TV remote, this telly uses cameras to track your eye movements so you can browse through its apps and channels just by peering around the screen. Haier.com

+ Google Gem Nexus

Little is known about Google's smartwatch other than it's likely to use Google's diary system Google Now, and work with its smart glasses. Google.com/play

9 MONTHS

TELLSPEC



A promising gadget that will tell you the allergens, nutrients and calories in your food by scanning it. Inside is a spectrometer that translates the data into info about what's on your plate. Tellspec.com

+ FABtotum

An all-in-one personal fabricator that houses a 3D printer and scanner, as well as a machine mill and laser cutter. Fabtatum.com

+ Skully

A prototype helmet that offers bikers a heads-up display (HUD), which warns if an object enters your blindspots and shows you the view from the back. Skullyhelmets.com



JUST LANDED: SAMSUNG GALAXY GEAR

FUTURE WATCH

Move over Dick Tracy, Michael Sawh tests Samsung's new smart timepiece

What is it?

It's a £300 watch that works a bit like a smartphone. The Galaxy Gear has its own touchscreen and you can download apps just like you can on a phone. It wirelessly connects to a smartphone or tablet to communicate between the two so you can read emails and text messages on the watch's screen. There's a speaker and two microphones packed in too, so you can make and receive calls if you're happy to accept that you're going to get some strange looks.

Why would I want one?

This is for you if you always have to be at the cutting edge. You'll certainly find it useful if you'd rather quickly glance at your watch to find out if someone has retweeted your hilarious photo than reach into your pocket to launch the Twitter app. You can talk to the Gear to set appointments and take pictures and shoot HD video with the built-in camera. And unlike Samsung's plastic smartphones, the Gear's stainless steel watch face and thin-as-a-smartphone design means it's a good-looking watch to wear.

How useful is it?

Talking at your wrist is going to make you look silly. But if you can ignore the



awkwardness of talking to a wristwatch, the Gear's call quality is really quite impressive. On the other hand, telling the Gear to set up a meeting is a frustrating process and it'd be much quicker to do it on your phone. There's also a fatal flaw with email notifications. Unless you use Samsung's own email service you will only see the subject and won't be able to read the actual message. However, the

built-in fitness-tracking tech actually shows promise and great potential. We installed Runtastic, one of the few useful apps to take out for a run, and it accurately measured our pace.

Should I buy one?

There aren't enough apps to really make it useful, unless you like changing clock faces or listening to Korean radio. There's still a lot of work to do to make this desirable, and it only works with a handful of Samsung smartphones and tablets. Just like the iPad, the second generation might be the one to set us alight. ■

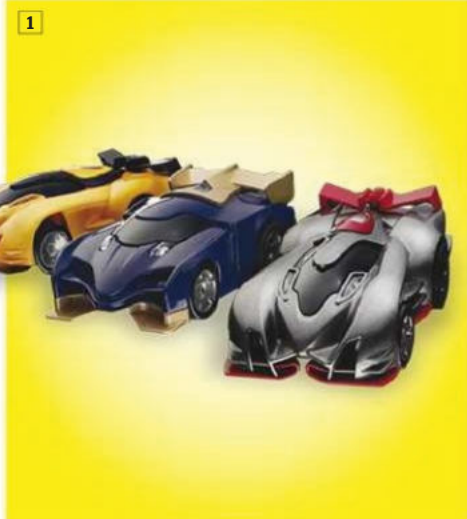
MICHAEL SAWH is reviews editor at trustedreviews.com

PEBBLE POWER

If you're really sold on the idea of a smartwatch, the Pebble is where you should be spending your money. It's smaller and lighter than the Gear and, at £100, costs significantly less. You can't take pictures or make phone calls, but you can receive email and text notifications, see Facebook feeds, control your music and download apps.

Crucially, it also works with both iPhones and Android phones and the back-lit e-ink display means it's easy to read in sunshine.





APPLIANCES OF SCIENCE

1 WACKY RACERS

With a chassis covered in sensors and a microprocessor inside, Anki cars are more like robot insects than remote-controlled toys. You connect to your car via Bluetooth on an iPhone to give it a personality like 'slow and safe', for example. As they race, the cars employ different strategies and react in real time to what's happening. The track is painted in ink embedded with positional code.

Anki Drive

Anki.com, \$200 starter kit (£125)

2 ROBOCHEF

If cooking a steak on a pan for six minutes (three minutes per side for a rare piece of meat) seems too much like hard work, the OptiGrill will do it for you. Sensors inside detect the thickness of your meat and how much there is of it, so when you hit the 'medium-rare' button, it knows exactly how long to cook the meat for to give you the perfect steak. It'll do the same for burgers, bacon, fish and more.

Tefal OptiGrill

Optigrill.tefal.co.uk, £129

3 SENSOR SENSATION

A carbon monoxide detector, non-contact thermometer, gas leak detector, lux meter, weather station and breath analyser are all packed into a sensing computer measuring just 6.8x2.8x1.2cm. The idea is that developers will create compatible smartphone apps that can reveal the purity of water, whether you've had too many drinks to drive, if there's carbon monoxide in the air and much else besides.

Sensordrone

Sensordrone.com, \$199 (£124) plus P&P

4 IT'S ALL IN THE WRIST

The latest smartphones are beginning to introduce fingerprint recognition as an extra level of security. But the creators of the Nymi don't think that's safe enough. Their wristband detects the unique wave pattern of a person's heartbeat and uses it as a means of verifying your identity, whether it's logging-in to your computer, phone or any other device that demands a sign-in.

Nymi

getnymi.com, \$79 (£48.79) plus P&P

5 GLOBEPOTTER

This glass bowl can help you grow tropical plants like orchids with no daylight and very little effort. The orb is fitted with a fan that continuously cycles the air through a carbon filter. Water in a reservoir beneath the plants is turned into a light fog by an ultrasonic mister every time the sensors detect the BiOrb's humidity falling below 75 per cent. And for sunlight and warmth there's six high-power LEDs.

BiOrb Air

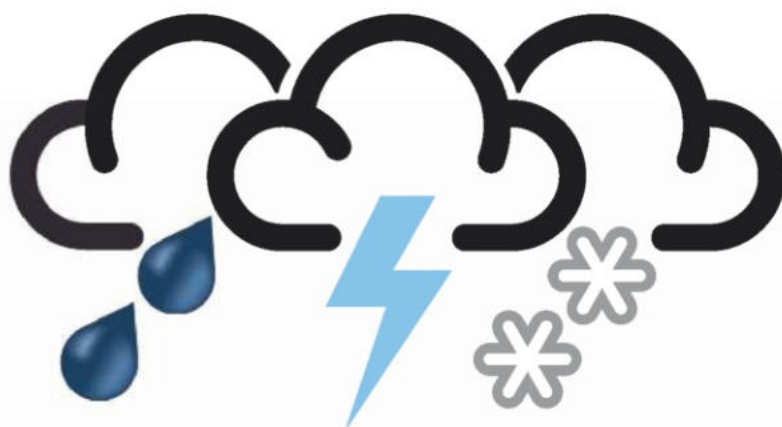
Biorbair.com, £399

6 HYDROGEN POWER

Unless you happen to be an avid mountaineer and you regularly find yourself days away from civilisation, there's probably not much call for a mini-hydrogen reactor that can charge your phone. That said, we can't deny we're not tempted by this device, which combines hydrogen with oxygen from the air to generate electricity, all the while puffing out tiny clouds of water vapour as a by-product. The steam age has arrived.

Brunton

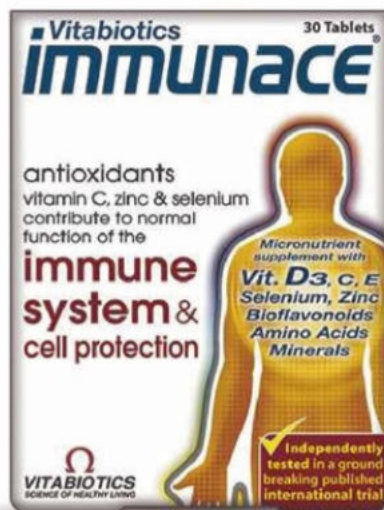
Brunton.com, \$169 (£105)



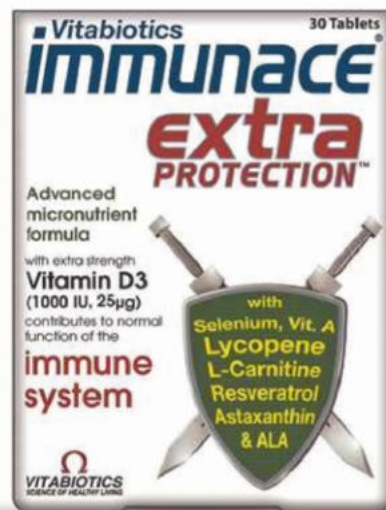
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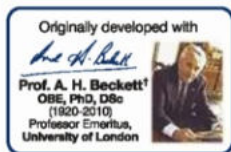
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ULTIMATE TEST

TABLET TAKFOVER



Compact tablets will be featuring on many letters to Santa this year, but which is the best? GORDON KELLY finds out...

BY THE END of 2013, more tablets will find new homes than PCs. Given that PCs have been around since the late 1970s and tablets only became popular with the launch of the iPad in 2010, that's a remarkable rise.

What has driven the meteoric growth is their simplicity and

convenience. Tablets offer intuitive touchscreen interfaces, great battery life and major leaps in speed and camera quality with each generation. Developers are jumping in too, producing lorry-loads of apps which have revolutionised both our work and our play.

Now there is a growing trend for smaller, more pocket-friendly tablets led by the iPad mini. With Christmas fast approaching, we decided now would be the ideal time to take a look at which of these mini marvels should misshape your stocking.





Screen size: 7.9-inch, 1,024 x 720 pixels. Camera: 5MP rear, 1.2MP front. Memory: 16GB/32GB/64GB. Size: 200 x 134.7 x 7.2mm. Weight: 308g



Screen size: 7-inch, 1,920 x 1,080 pixels. Camera: 5MP rear, 1.2MP front. Memory: 16GB/32GB. Size: 200 x 114 x 8.65mm. Weight: 290g

IPAD MINI

Price: £269-£529

➔ THE KING OF tablets now has a baby brother. Steve Jobs famously declared there would never be a smaller iPad, but the mini is a triumph. Its design is sleeker, thinner and less than half the weight of the 10-inch iPad, yet provides 80 per cent of the screen size. Battery life is strong too, matching the iPad's 10 hours of surfing on a single charge.

The mini also benefits from the huge collection of high quality apps made for the iPad, all of which are compatible. Lastly, the mini's starting price of just £269 is significantly cheaper than the £399 cost of an entry-level iPad, though this spirals quickly if you start adding larger storage capacities and optional 4G.

The problem for the iPad mini is, while it compares very favourably to the iPad, it is less successful compared to other small tablets. Noticeably, the sharpness of screen is among the lowest in the sector and its speed is sluggish, meaning many of the latest games don't run all that smoothly.

Tablets aren't known for their camera quality and the mini does little to change that. It's fine for quick snaps, but don't expect the quality offered by premium smartphones. All in all, the iPad mini is a competent, stylish and affordable tablet. It's also becoming a little dated, but with an upgrade due soon (see below), this might not be the case for long.



GOOGLE NEXUS 7

Price: £199-£299

APPLE HAS RULED the tablet roost since it launched the iPad, but Google's Nexus 7 and 10 have quickly become its most credible rivals. The 2013 edition of the Nexus 7 cranks the pressure up even higher, besting the iPad mini in almost all areas.

Most noticeable is the difference in screen quality, with the Full HD resolution of the Nexus 7 producing a razor-sharp viewing experience that is perfect for reading, web surfing and watching movies. The Nexus 7 is also much faster than its Apple rival and will happily play the latest games without hesitation. Despite all this the Nexus 7 is 18g lighter and a whopping £70 cheaper than the iPad mini – a gap which widens

further when larger capacities and optional 4G are added.

But the Nexus 7 doesn't have everything its own way. It may be lighter, but it gives up almost an inch of screen size and battery life is a fraction shorter, giving nine hours of active use between charges. That said, the Nexus 7 offers built-in wireless charging which saves on cable clutter.

Unlike other Android tablets, the Nexus range also gets Google's latest updates the moment they come out. These often bring major enhancements, so this is a real bonus. Android itself lacks the number of tablet apps found on Apple's iOS, but it is hard to look beyond this sophisticated bargain.



5 TABLETS TO SAVE YOUR PENNIES FOR

If none of the tablets in our group test made your pulse quicken, don't worry: these mouthwatering alternatives are on their way

NEW IPAD/IPAD MINI

Just as this issue went to press, Apple announced new models of its iPad tablets. The new iPad mini has a high-resolution Retina Display, while its bigger brother, the iPad Air (pictured), is just 7.5mm thick and weighs 454g, making it the thinnest and lightest model to date.



LG G PAD

November brings a major Nexus 7 rival. It matches the 7's specs, but offers a larger 8.3-inch screen and expandable Micro SD storage. Weight and price will both be slightly greater, but this could be the mini Android tablet to beat.





Screen size: 7-inch, 1,024 x 600 pixels. Camera: 3MP rear, 1.3MP front. Memory: 8GB, Micro SD expansion slot. Size: 188 x 111 x 10mm. Weight: 299g

SAMSUNG GALAXY TAB 3 7.0

Price: £179.99

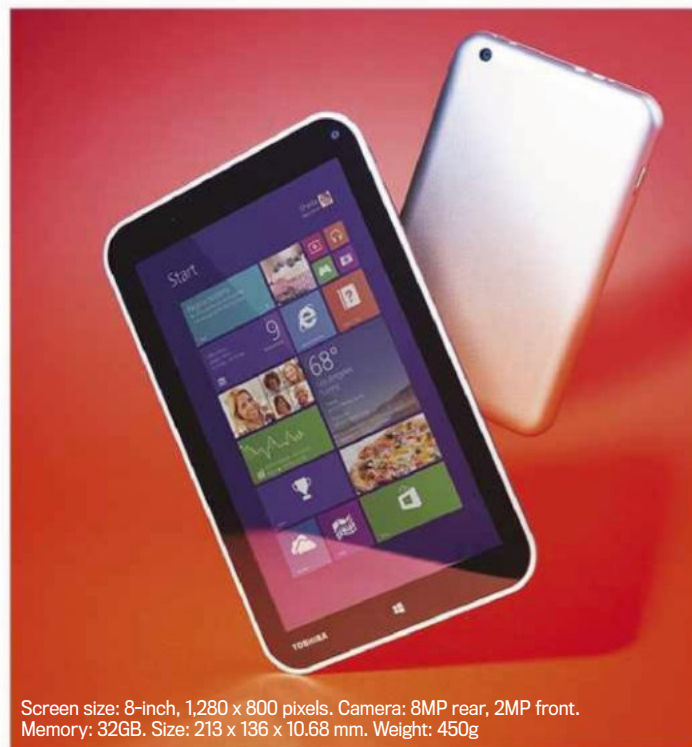
PRICE HAS BECOME a key factor in the appeal of smaller tablets, and Samsung's verbosely named Galaxy Tab 3 7.0 is one of the cheapest around. Normally such bargain-basement pricing is an immediate cause for suspicion but on the surface this tablet has a lot going for it, with good build quality, sleek design and a gently curved back which makes it pleasant to hold.

The trouble is that if you look at it a little more closely, problems start to arise. The screen is the first giveaway of cost-cutting in the manufacturing. The Galaxy Tab 3 7.0 offers the lowest resolution of any tablet on test and unfortunately this means neither text nor video is as sharp as it

should be. Given a tablet's role as a reading and media consumption device, this is a significant flaw.

There are other shortcomings, too. The Galaxy Tab 3 7.0 is a little underpowered compared to the competition so it isn't ideal if you want to play the latest games, and the rear camera is disappointing too, requiring strong lighting to get usable pictures.

On the plus side battery life is good and, unlike the Nexus 7 and iPad mini, you can easily expand storage via its Micro SD slot. Unfortunately the Galaxy Tab 3 7.0 comes with half the storage of its rivals, so what could've been a useful differentiator merely highlights its false economy.



Screen size: 8-inch, 1,280 x 800 pixels. Camera: 8MP rear, 2MP front. Memory: 32GB. Size: 213 x 136 x 10.68 mm. Weight: 450g

TOSHIBA ENCORE

Price: £249.99

IT IS LONG overdue, but Windows 8 is finally ready for the small screen and the Toshiba Encore will be one of the first devices to bring it to market.

From a hardware perspective the pre-production Encore model we tested proved a mixed bag. The 8-inch screen is the second largest in this test, but the resolution is lacking, making reading acceptable but not as enjoyable as on the Nexus 7. The Encore is also thick and heavy for its size, but it does squeeze in 32GB of storage as default and offers the only 8MP camera so far on a small tablet.

These pros and cons extend to software as well. In its favour, Windows 8 seems to offer the

best of tablet and laptop with a finger-friendly touchscreen user interface plus full access to the traditional Windows desktop as well as the ubiquitous Office suite. There are issues, though: the former lacks dedicated tablet apps and the latter is fiddly to navigate on an 8-inch screen. Battery life struggles against the Android and iOS tablets, too.

So while the Encore gives a glimpse of Windows's potential on future tablets, we'd suggest it might be a good idea to wait for the next generation to come along before taking the plunge.



GORDON KELLY is a technology writer for TrustedReviews.com

TESCO HUDL

We couldn't test this at the time of writing but its good looks, decent specs and very affordable £119 RRP mean Tesco's debut tablet is one for bargain-hunters to watch.



AMAZON KINDLE HDX

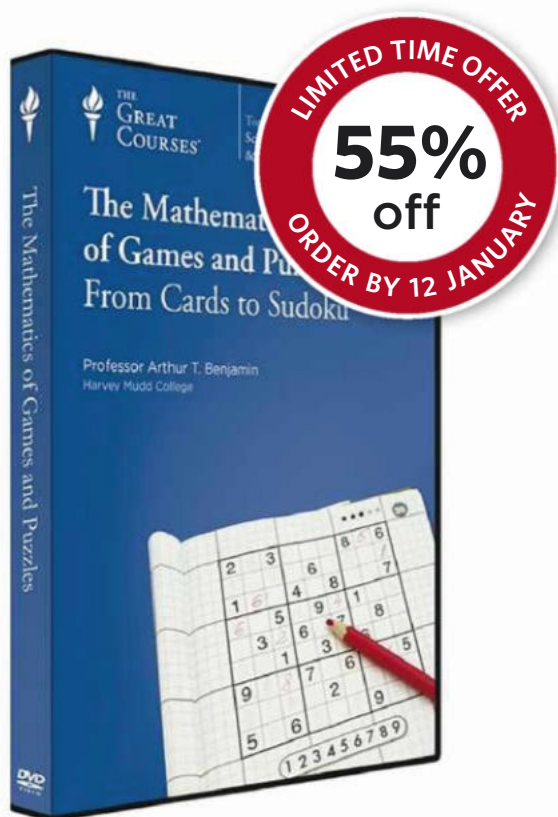
If you don't mind excessive Android customisation, the HDX range will essentially put a Nexus 7 in your hands for less money. Both the 7-inch and 8.9-inch HDXs also have 'Mayday', an instant live customer service assistant, making them technophobe-friendly.



GOOGLE NEXUS 10

The upgraded 7 won't be alone for long. The 10-inch variant will be on sale from November with more muscle than its smaller brother, a slimmed-down design and an iPad-beating price as it goes head-on with Apple's impending flagship.





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THE EXISTENCE OF ISOTOPES

BY CHERRY LEWIS

They are used in everything from cancer treatments to smoke detectors and atom bombs, but it wasn't until the 20th Century that we unravelled the mystery of chemically identical elements

E

XACTLY 100 YEARS ago this month, on 4 December 1913, a paper was published in the journal *Nature* that documented one of the most important discoveries ever made. It was the culmination of many years of experiment and was to revolutionise the

way we understand our world.

It was the Greek philosopher Democritus who first put forward an atomic theory of the Universe. According to this, objects differed only in the shape, position and arrangement of their atoms. So, for example, atoms of a liquid were smooth and round while atoms of a solid were jagged so that they could catch on to each other and hold fast. Democritus coined the word 'atom' which in Greek (atomos) means 'undivided' because, according to his theory, atoms could not be destroyed. Two thousand years elapsed before the theory developed much further.

In 1789 a French chemist, Antoine Lavoisier, listed the existence of 92 different types of matter. These were

the elements, the building blocks of which everything in the Universe is made, but the dilemma was how to classify them; what characteristics did they have in common that would allow them to be ordered? Had Lavoisier lived, he may have solved this problem, but he was beheaded in 1794 during the French Revolution. An Italian mathematician lamented at the time, 'It took them only an instant to cut off his head, but France may not produce another such head in a century'. As it was, the challenge of ordering the elements was taken up by an Englishman, John Dalton.

UP IN THE AIR

Dalton was concerned with the nature of gases. Around 1803, having shown that evaporated water exists in air as an independent gas, Dalton wondered how water and air could occupy the same space at the same time. He reasoned that if each were composed of discrete particles (what we now think of as atoms), evaporation might be viewed as a mixing of

water particles with air particles. It was while performing a series of experiments on mixtures of gases to prove this idea that he was led to determine 'the number and weight of all chemical elementary particles'.

Exactly how he arrived at this idea remains unexplained, since much of his work was lost in a bombing raid during the Second World War. However, a paragraph added to a paper published in 1805, after it had been read to the Manchester Literary and Philosophical Society in 1803, said the following: "An enquiry into the relative weights of the ultimate particles of bodies is a subject, as far as I know, entirely new: I have lately been prosecuting this enquiry with remarkable success." This was followed by the first rudimentary table of atomic weights.

Dalton's atomic theory not only identified that each element is distinguished by the characteristic weight of the atoms of which it is composed, but he also showed that all matter is composed of atoms, that all atoms of the same element



The physicist Francis Aston used this mass spectrograph, to reveal two isotopes of neon in 1919

> IN A NUTSHELL

They are chemically identical to other elements, but discovering isotopes led to a revolution in science and technology, opening up applications in archaeology for carbon dating, cancer therapies and nuclear weapons.

→ are identical, and that different elements have different types of atoms. However, he also thought that atoms cannot be made or destroyed, an idea that was not challenged for almost another hundred years.

In 1895, Wilhelm Röntgen, a German physicist, observed a mysterious source of energy being emitted as invisible rays from a Crookes tube. When he placed his wife's hand over a photographic plate and in the path of these rays, Röntgen was able to develop a remarkable photograph that showed the bones in her hand, surrounded by the shadow of her flesh. This extraordinary image was the

first X-ray ever seen. The following year Henri Becquerel, a French physicist, wondered whether there was any connection between the newly discovered X-rays and the reason why uranium glowed in the dark. He placed some uranium in a drawer with a photographic plate covered with black paper. On removing it the plate was seen to be fogged, proving that uranium also emitted invisible rays.

Initially Becquerel's discovery did not arouse much attention, overshadowed as it was by Röntgen's X-rays because of the medical possibilities. But working in Paris at that time was a newly married

couple, Pierre and Marie Curie, both of whom were physicists. Following the birth of their first child in 1897, Marie decided to make a systematic investigation of Becquerel's 'uranium rays'. Progress was quick. Within a few days she had discovered that another element, thorium, gave out the same rays as uranium. Marie concluded that the rays being emitted from uranium and thorium were not the result of a chemical reaction, but came directly from the element itself. She called the phenomenon 'radioactivity'.

Later that year the atom finally lost its status as a fundamental particle that could not be subdivided when

THE KEY EXPERIMENT

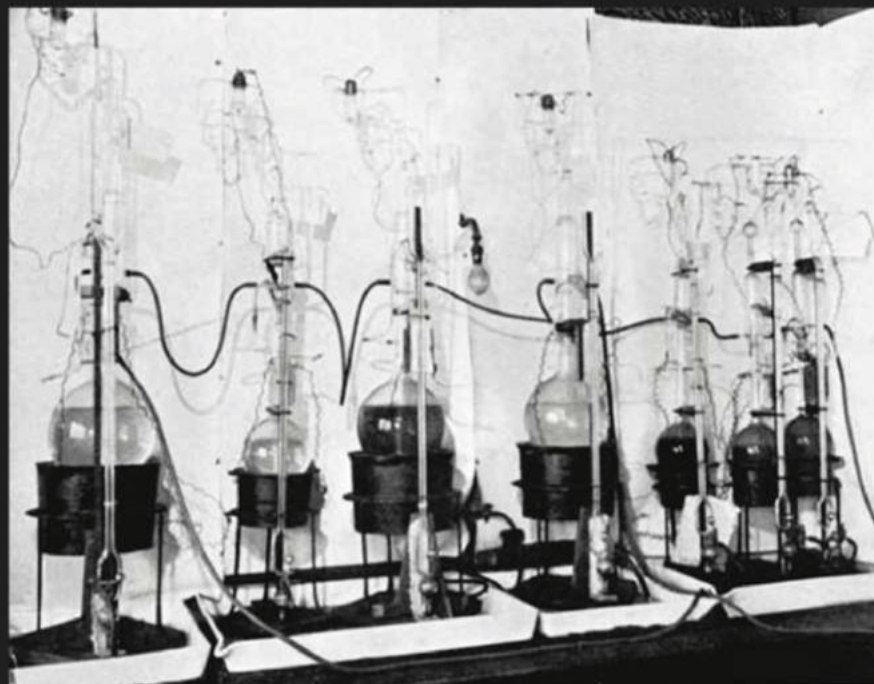
By studying the decay products of uranium and thorium, Frederick Soddy and his assistant Alexander Fleck were able to identify the existence of isotopes

IN 1910, UNABLE to chemically separate several decay products of uranium and thorium from their parent elements, Frederick Soddy suspected that he had discovered a new chemical phenomenon. The next year, a young chemist, Alexander Fleck, joined Soddy's laboratory and was set the task of systematically studying the chemical and electrochemical nature of all the known decay products – then some 40 elements.

By the end of 1912, Fleck had shown conclusively that 'All are chemically indistinguishable from one or other of the elements occupying the last 12 places of the periodic table'. Furthermore, he demonstrated that whenever two or more elements came to occupy the same place in the periodic table – as a result of the expulsion of alpha or beta rays – then they were inseparable from one another and identical in chemical

character. This was regardless of all other factors such as the element's atomic weight, its radioactive character and the nature of the radioactive changes in which it was produced.

These remarkably consistent results led Soddy to propose the concept of isotopes in December 1913. Isotopes were positively identified after the First World War when Francis Aston recognised two isotopes of neon with his new mass spectrograph.



Frederick Soddy's apparatus which was used to detect the production of helium from uranium and thorium



The pioneer: Frederick Soddy

James Joseph Thomson detected the electron at the Cavendish Laboratory in Cambridge. Working under him was a young New Zealander, Ernest Rutherford, who the following year (1898), at the age of only 27, was appointed Professor of Physics at McGill University in Montreal, Canada.

There, Rutherford pursued his work on radioactive materials. He established that there were several kinds of radiation, each of which emitted different particles – alpha particles, beta particles and gamma rays. As part of this work, the chemical nature of the emitters themselves came under scrutiny, so Rutherford looked for a skilled chemist to work with. He found Frederick Soddy, a young assistant in the chemistry labs at McGill.

PIONEERING PARTNERSHIP

The pair worked well together, and in 1902 astounded the scientific community with the announcement that one element could change into another. Incredibly, it appeared that in the process of emitting ‘mysterious rays’, completely new types of matter were created, the chemical and physical properties of which were quite distinct from the parent atom: radium became radon – a solid became a gas.

Suddenly radioactivity was all the rage and Rutherford and Soddy’s ‘decay’ theory of the break-up of atoms was a topic of supreme interest not just to scientists, but to the world at large. Journalists besieged Rutherford’s laboratory and doctors wrote to him about ‘a trial of the inhalation of radium gas as a cure for tuberculosis’, and ‘the interesting effects produced when radium is brought near the eye’. Soddy later recalled what it had been like to work with Rutherford at that time: “I abandoned all to follow him, and for more than two years scientific life became hectic to a degree rare in the lifetime of an individual.”

Following their success, in March 1903, Soddy elected to join Sir William Ramsay at University College in London to examine more fully the gaseous products of decay. When Rutherford visited England later that summer they together established that in the ‘decay chain’ that started with an unstable ‘parent’ atom of uranium, a ‘daughter’ atom of radium was produced and helium liberated. In turn the unstable radium atom decayed to its ‘daughter’ product radon, also

CAST OF CHARACTERS

The great minds that unravelled the true nature of the elements



Democritus (ca. 460–370 BC) lived in Ancient Greece and was known as the ‘laughing philosopher’ because of his emphasis on ‘cheerfulness’. He was a founder of the atomist theory, which held that there are small indivisible bodies from which everything else is composed, and that these move about in an infinite void.

John Dalton (1766–1844) is one of the most important figures in chemistry.

In 1805 the English physicist published the first table of atomic weights, recognising that each element is distinguished by the characteristic weight of its atoms, that all matter is composed of atoms, and that all atoms of the same element are identical.



Marie Curie (1867–1934) was a Polish chemist inspired by Henri Becquerel’s discovery of ‘uranium rays’, which she termed radioactivity. She separated radium in sufficient quantities to allow for its characterisation and the study of its properties. In 1903, Becquerel and the Curies received the Nobel Prize in Physics for their work on radioactivity.



Ernest Rutherford (1871–1937) was a New Zealand physicist who investigated the phenomenon of radioactivity.

Working in Canada with his assistant Frederick Soddy, they proposed that radioactivity results from the disintegration of atoms, for which Rutherford won the Nobel Prize in 1908. He is credited with splitting the atom in 1917, when he also discovered the proton.



Frederick Soddy (1877–1956) worked in his early years on the disintegration products of radioactivity. In 1921 he won the Nobel Prize in chemistry for his discovery of isotopes, but after this became disillusioned with science, believing his work on radioactivity had made him sterile. His later writings were on political economy and monetary theory.



TIMELINE

The idea of atoms stretches back 2,000 years, but the nature of isotopes wasn't realised until the 20th Century



Democritus puts forward an atomic theory of the Universe and coins the word 'atom'. According to this theory, atoms cannot be destroyed and exist in a void.

400 BC

1789

French chemist, Antoine Lavoisier, lists the existence of 92 different types of matter. These were the elements.

John Dalton determines the atomic weight of atoms, demonstrating that all matter is composed of atoms and that different elements have different types of atoms. He still thinks atoms cannot be subdivided.



1805

1896



Henri Becquerel (left) discovers mysterious rays being omitted from uranium, which in 1898 Marie Curie calls radioactivity. During this work Curie went on to discover other radioactive elements, radium and polonium.

Ernest Rutherford and Frederick Soddy announce their discovery of radioactive decay in which one element spontaneously changes into a completely different one through the emission of various particles. Helium is liberated in the process.



1902

1913

After two years of experiments, Alexander Fleck confirms that many radioactive decay products are chemically inseparable from each other, but have different weights. This leads Frederick Soddy to publish his discovery of isotopes.



releasing helium in the process.

And so on until eventually eight atoms of helium had been discharged and a completely new stable element emerged. We now know this element to have been lead.

After a year in London, Soddy took up the post of Lecturer in Physical Chemistry and Radioactivity at the University of Glasgow where, over the following 10 years, he helped to clarify the relationship between the ever-growing number of radioactive elements and the periodic table. But during this period a number of chemists in different laboratories around Europe were reporting that several elements appeared to be indistinguishable as far as their chemical reactions were concerned, even though they could be separated physically. Radiothorium, for example, a decay product of thorium, was chemically inseparable from thorium, although it could be distinguished physically. What was going on?

Soddy examined the problem and he too found that it was impossible to separate thorium X from mesothorium and radium, concluding that the three elements were chemically identical. As he reported later: "From this date [1910] I was convinced that this non-separability of the radioelements was a totally new phenomenon, quite distinct from that of the most closely related pairs... and that the relationship was not, as usually supposed, one of close similarity, but of complete chemical identity."

IDENTICAL ELEMENTS?

The following year, 1911, Soddy resolved the situation when he advanced his 'general displacement' law. In this he stated that when an alpha particle was expelled during radioactive decay, the element shifted two places along the periodic table in the direction of lower mass; the subsequent loss of two beta particles from the new element would then return it to its original position. When the element was back in its place on the periodic table, it would become the same element it had been originally, but its weight would be different. This explained why the daughter element could not be chemically separated from its parent, but could be distinguished by its different weight. Studies over the next year or so by Soddy's assistant, Alexander Fleck,

NEED TO KNOW

Five key terms that will help you understand isotopes

1 ALPHA, BETA AND GAMMA DECAY

Alpha decay occurs when the nucleus ejects a helium nucleus. Beta decay happens when the nucleus emits an electron or positron and a type of neutrino. In gamma decay, energy of an excited nucleus is emitted as a gamma ray.

2 ISOTOPE NUMBER

The number of neutrons and protons in the nucleus added together. An atom of lead derived from the decay of uranium 238 is 'lead-206' because it contains 82 protons and 124 neutrons ($82 + 124 = 206$), thus '206' is the isotope number.

3 MASS SPECTROGRAPH

An instrument used to determine the masses of atoms. A beam of charged particles is passed through an electromagnetic field, separating particles of different mass. The resulting spectrum is recorded on a photographic plate.

4 RADIOTHORIUM

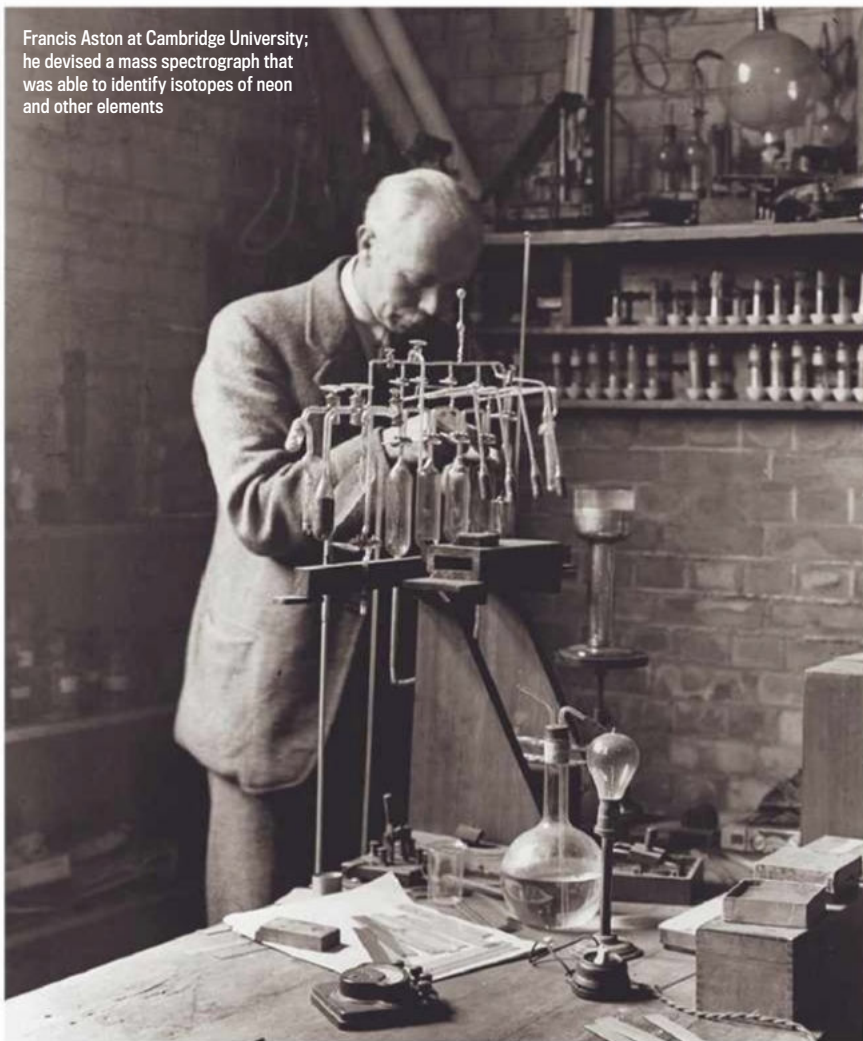
Radiothorium and thorium X are both defunct terms – today they're known as thorium-228 and radium-224. Mesothorium came in two states, I and II, now called radium-228 and actinium-228.

confirmed that the same effects were found in many other decay products.

It was while discussing this new concept at a dinner party given by Soddy's father-in-law, himself an industrial chemist, that a family friend, Dr Margaret Todd, suggested the name 'isotope' (from the Greek, *isos* topos, meaning 'same place') for atoms that were chemically identical but had different weights. Soddy used the term 'isotopes or isotopic elements' for the first time in his article *Intra-atomic Charge*, which was published in the journal *Nature* on 4 December 1913.

On reading this article, the physicist Francis Aston began to suspect that isotopes of other elements might exist, but the First World War prevented him from testing this hypothesis. On returning to Cambridge in 1919, he

Francis Aston at Cambridge University; he devised a mass spectrograph that was able to identify isotopes of neon and other elements



developed the instrument that became known as the mass spectrograph, a device that showed the chemical constituents of a sample as distinct lines. He showed that neon produced two spectral lines at mass 20 and 22, proving that neon had two isotopes.

At the time of Soddy's discovery, the nucleus of an element had only just been discovered (by Rutherford in 1911), and it was still unknown that the nucleus itself was comprised of two kinds of particle – protons and neutrons. We now know an element's position in the periodic table is dictated not by atomic weight but atomic number (the number of protons).

The discovery of isotopes revolutionised science. In medicine, isotopes are used in bone imaging and as tracers to detect tumours and blood clots. Gamma rays of cobalt-60 are used in radiotherapy to kill cancer cells; it also kills bacteria in food. In archaeology, carbon-14 determines the age of an object, and geologists use

isotopes of uranium and lead, amongst others, to determine the age of rocks. Isotopes are also used in the sensors of smoke detectors and, most famously, it's the isotope uranium-235 that is found in nuclear weapons.

In 1921, Frederick Soddy was awarded the Nobel Prize in Chemistry. A year later, the Prize was awarded to Francis Aston for his discovery 'of isotopes in a large number of non-radioactive elements'. They were fitting awards for one of science's greatest discoveries. ■

Dr Cherry Lewis is a geologist and the author of *The Dating Game: One Man's Search For The Age Of The Earth*

Find out more



Listen to an episode of *In Our Time* on chemical elements, with Melvyn Bragg and guests.
<http://bbc.in/JrBI8H>

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TO DO LIST

PLAN YOUR MONTH AHEAD WITH OUR EXPERT GUIDE

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Walking With Dinosaurs: The 3D Movie

King of the hill: one dino's journey from runt to ring leader is charted in a brand new film

→ IT'S NEARLY 15 years since *Walking With Dinosaurs* first wowed viewers with its life-like dinosaurs in real-world backdrops. Now, the series is set for a three-dimensional reboot with *Walking With Dinosaurs: The 3D Movie*.

The film follows the plight of a young Pachyrhinosaurus (a close relative of the Triceratops) called Patchi who's born the runt of the litter and (yep, you guessed it) grows up to become the leader of the herd. His nemesis? A blue, iridescent Gorgosaurus called Gorgon.

And in case you're wondering, yes, the dinosaurs talk. But don't make the mistake of thinking this is an updated version of *The Land Before Time*. Produced by BBC Earth and Evergreen Studios, the film's makers have worked closely with palaeontologists and palaeo-artists to ensure the dinosaurs' behaviour complies with current theories to make them look and act as realistically as possible.

"A lot of Pachyrhinosaurus fossils have come to light in the last few decades," says Dr Stephen Brusatte, a researcher at Edinburgh University and consultant palaeontologist on the film. "A

huge bone bed in Canada shows that thousands of Pachyrhinosaurus lived there – good evidence that they formed herds. They were the bison of the Late Cretaceous period."

The movie, which is set in Alaska around 70 million years ago, superimposes the animated dinosaurs onto backgrounds shot in Alaska and New Zealand. The dinosaurs were modelled from the bones up with the help of palaeontologists and then their muscle systems, skin and, in some cases, feathers were added on top.

"That's not artistic licence: we now have tens of thousands of fossils of feathered dinosaurs, most of them from China where they were buried almost immediately by a volcanic eruption." And, enthuses Brusatte, it'll be a first for film fans. "There weren't any feathered dinosaurs in *Jurassic Park*, so for a lot of viewers it'll be the first time they see them."

JAMES LLOYD

Walking With Dinosaurs: The 3D Movie is released in UK cinemas on 20 December

DON'T MISS!



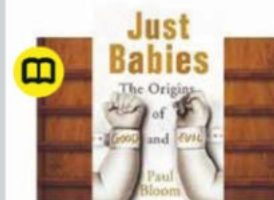
Exchanges At The Frontier

Henry Markham, director of the Blue Brain project, gives a talk on his mission to build a mind. **p132**



The Science Of Doctor Who

Celebrating 50 years of the Doctor, Prof Brian Cox looks at the science behind the show. **p134**



Just Babies

Paul Bloom's new book examines how our sense of morality and emotions like disgust are fostered when we're babies. **p137**



VISIT

EVENTS & EXHIBITIONS

WITH JHENI OSMAN

22 NOVEMBER

Back To The Moon For Good?

Royal Observatory Greenwich, London, 7pm-9pm, £8 adults, £6 members and concessions, www.rmg.co.uk



THE DAY ARMSTRONG walked on the Moon, few would have believed that 45 years later only 11 people would have followed in his footsteps. Visions of lunar colonies died with the Space Race. So is the thirst to return to the Moon still there? A panel of engineers, architects and authors discuss the when, why and how of the next lunar landing.

22 NOVEMBER - MAY

Everyday Relics

MOSI, Manchester, free, www.mosi.org.uk



STUFFED FULL OF industrial gems from a Spitfire to replicas of early steam locomotives, MOSI is packed with treasures. Artists Lucy and Barney Heywood have picked some fascinating objects from the MOSI Collection, and brought their stories to life through sound and projection. Explore their thought-provoking work in the Highlights Gallery.

29-31 NOVEMBER

Robot Safari EU

Science Museum, London, free, www.sciencemuseum.org.uk



GET READY, THEY'RE coming! Don't worry, it's not a Dalek invasion ready for the *Doctor Who* Christmas Special. From across Europe, real robots modelled on living systems are converging on the Science Museum for a week. See these biomimetic creations in action, quiz the roboticists and find out how they'll help us understand nature.

JHENI OSMAN is a science writer and the author of *100 Ideas That Changed The World* (BBC Books, £9.99)

EDITOR'S CHOICE



Minecraft just isn't enough for some people: Henry Markram plans to build a working human brain using supercomputers

22 NOV - 19 DEC

Exchanges At The Frontier

Wellcome Collection, London, free but booking required, www.wellcomecollection.org



DEEP BLUE: 2, Kasparov:

1. That was the score in the 1997 match between the computer and the chess grandmaster. But while a computer might be able to win a game of chess, could it ever really outdo the human brain? Sure, they can crunch complex calculations and store gigabytes of data, but our grey matter is better at adapting to change and learning through observation and experiment.

The Blue Brain project is attempting to build a virtual replica of the human brain by harnessing the power of supercomputers. Such

a feat requires processing power equivalent to billions of laptops. On 21 November, join the director of this ambitious project, Henry Markram, as he talks about the challenges and potential benefits.

This is just one in a series of Exchanges At The Frontier talks that the Wellcome Collection is running with the BBC World Service. Others include a bipolar clinical psychologist discussing her condition, a molecular biologist on 'talking' bacteria, and a biologist on how to trick locust swarms into self-destruction. Locust burger, anyone?

29 NOVEMBER

Life Is What You Make It

Royal Institution, London, 8pm-9.15pm, £11



'READING' DNA - BEEN there, done that. Everything from the human genome to that of the Brown Norway rat has been sequenced. But 'writing' DNA is another matter. Can we reprogram biology and generate new life forms? Prof Paul Freemont (pictured), from the Macromolecular Structure lab at ICL explores the new challenges of synthetic biology.

9 DECEMBER

Night Safari: Africa

 Natural History Museum, London, 7-10pm, £28, www.nhm.ac.uk


NO NEED TO go to Africa for your safari fix. While the big five game aren't lurking in the depths of the Natural History Museum, hiding behind the scenes are all sorts of other intriguing creatures. Grab a drink and join a tour where you can chat one-on-one with scientists like Richard Sabin (pictured), and explore the museum at night.

11 DECEMBER

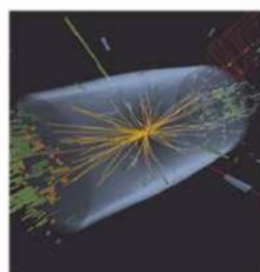
Café Scientifique Oxford

 Oxford University Museum of Natural History, 7pm, tinyurl.com/ondsztu


LIKE MAN UTD vs Man City, science and meditation have challenged one another throughout history. Investigating the science behind meditation and the concept of 'mindfulness' is Dr Barbara Gabrys of the Mathematical, Physical and Life Sciences Division at Oxford University. All together: ohmmm...

UNTIL 16 FEBRUARY

Hunting The Higgs Boson

 National Museum of Scotland, Edinburgh, free, www.nms.ac.uk


THE BIG BRAINS at CERN are now certain that we've found the Higgs boson, validating the billions spent building the Large Hadron Collider. Phew! This exhibition tells the story of the search for the 'God Particle', from its first proponent to its discovery 48 years later, and the ongoing quest to determine the structure of the Universe.

SPEAKER OF THE MONTH


5-7 DECEMBER

Michael Rosen

Science Museum, London, 11am and 1pm, adult £12, child £9.50, family and school tickets available, www.sciencemuseum.org.uk

→ Who is he?

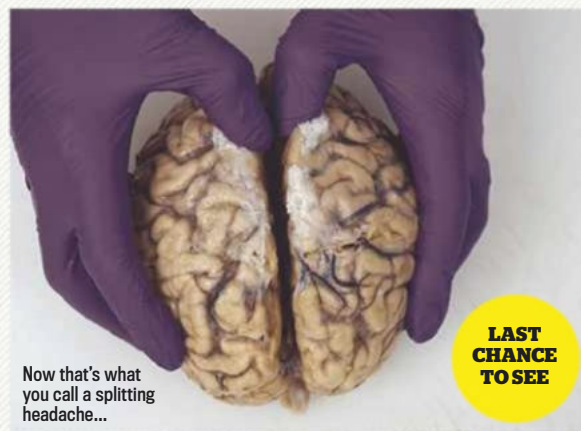
Rosen is a legendary children's author who has written numerous award-winning poetry collections, as well as non-fiction and picture books. He was the Children's Laureate from 2007-2009 and is the Visiting Professor of Children's Literature at Birkbeck, University of London.

What's he talking about?

Centrally Heated Knickers! An intriguing title for an eclectic, electric show. Set to an original musical score and performed live with the Homemade Orchestra, this musical extravaganza attempts to answer big (and little) science questions of the day. Through rhyme and rhythm, Rosen reveals how ears work, how music is made and, crucially, whether building electric circuits can help keep our knickers warm.

UNTIL 4 JANUARY

Brains: The Mind As Matter

 MOSI, Manchester, free, www.mosi.org.uk


Now that's what you call a splitting headache...

→ EVER HEARD THE brain described as 'tofu-like', yet never actually tried tofu? Think of the consistency of slightly solidified toothpaste... If you want to see a real brain in the flesh, get up close (but not personal) with some at this exhibition. Also on display are manuscripts, artefacts, video and photography that explore the brain's physiology and emotions. Discover the lengthy quest to manipulate and decipher this incredibly complex organ, and the secrets hidden within its 100 billion neurones and 100 trillion synapses.



WATCH

TV, DVD & BLU-RAY

WITH TIMANDRA HARKNESS

NOVEMBER

The Great Penguin Rescue

Eden, November TBC



PENGUINS DON'T JUST live in Antarctica. They're found as far north as Australia and South Africa, where this series is set. Presenter Michaela Strachan, who's lived there for 10 years, joins a local wildlife organisation to rescue late-hatching chicks. Being surrogate mother to 750 chicks is a demanding job, and we're looking forward to watching her dive into the sea, catch 750 fish suppers and regurgitate them into 750 hungry beaks. Or - more likely - do some stuff with little penguin-sized spoons.

FROM 10 NOVEMBER

Shaun Ryder On UFOs

History, starts 10 November, 9pm

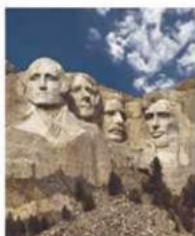


YES, THAT SHAUN Ryder, the lead singer of the Happy Mondays. Since spotting something hovering above his Salford home at an impressionable age, he's been a firm believer in flying saucers. Now he's on a quest from Manchester to Chile, interviewing academics, sceptics and 'alien abductees' in an attempt to separate reality from fantasy. Because obviously Shaun Ryder's the best person to sort *those* kinds of quandaries out. Or perhaps it's because Danny Dyer was otherwise engaged.

FROM 11 NOVEMBER

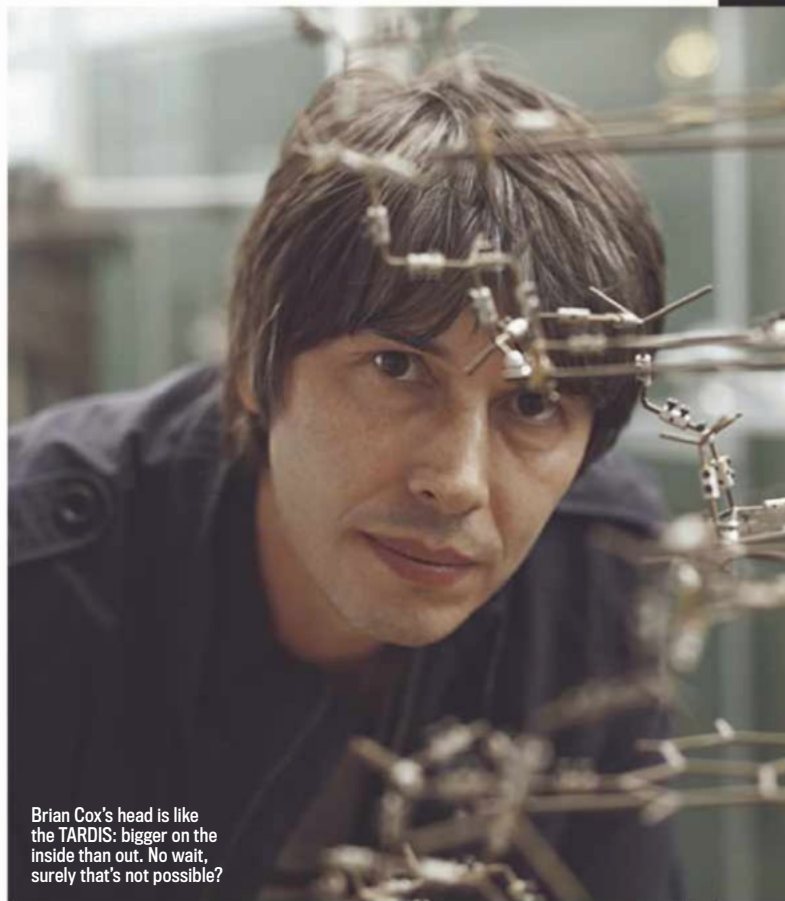
Brad Meltzer's Decoded

H2, Mondays from 11 November, 9pm



FROM THRILLERS TO inspiring kids' books, bestselling author Brad knows the importance of historical research. This new 11-part series gives him a chance to explore the odder fringes of American history: Did Billy The Kid really die? What is Mt Rushmore's hidden meaning? Was General Patton murdered by a hit squad on the orders of Dwight D Eisenhower? You may not be convinced by some of the wilder conspiracy theories he uncovers, but we can be pretty sure of great plots and a twist at the end of a story. Why 11 episodes? We can't tell you...

TIMANDRA HARKNESS is a stand-up comedian and a presenter on BBC Worldwide's YouTube channel Head Squeeze



Brian Cox's head is like the TARDIS: bigger on the inside than out. No wait, surely that's not possible?

14 NOVEMBER

EDITOR'S CHOICE

Brian Cox's The Science Of Doctor Who

BBC Two, 14 November

➔ HOW DO YOU give science the glamour of Hollywood? You invite a mix of fans and fellow celebs to form a friendly audience, you book the most prestigious venue you can find, and you invite the most famous name in your contacts book to present an evening of things to make you go "Gosh!" and "Wow!". So in 2011, the BBC booked the Royal Institution auditorium and hired the George Clooney of physics to present an evening of astronomy to the great and the good of popular science. *A Night With The Stars*, featuring Professor Brian Cox, hit the spot.

And now he's back with the same winning formula and

a topic that's probably even more irresistible - *Doctor Who*. In case you've been living on the planet Skaro, it's the Doctor's 50th anniversary this year, and Prof Cox goes back to the series' educational roots with a serious look at the science behind the fiction.

From centuries-old science to the very latest discoveries, chemistry, physics and maths are drafted in to answer the tough questions: Is time travel possible? How would you build the TARDIS? And is it true that in space, nobody can hear you swear like Malcolm Tucker?

If you miss it, it's on iPlayer till the end of the month.

14 NOVEMBER

Meet The Sloths

Animal Planet, 14 November, 8pm



MOVE OVER, MEERKATS, there's a new cute creature on the block, and this one hangs upside down – though admittedly, a creature that spends enough time asleep for algae to turn its fur green may not have the same instant appeal. Notoriously shy in the wild, they've been filmed in the Sloth Sanctuary of Costa Rica, South America. Over 150 injured and orphaned sloths, er, hang out, under the watchful eye of carers and scientists.

18 NOVEMBER

You Have Been Warned

Discovery Science, starts 18 November, 8pm



WATCHING CRAZY YOUTUBE clips is a guilty pleasure. You suspect somebody got hurt in the making of this video, or at least lost all their dignity forever, but it's *sooo* funny. Well, relax – the series that justifies all those internet clips by getting experts to explain the science is back. This season includes people jumping out of helicopters without a parachute, and getting much too close to volcanoes. Experts will explain why they're not dead and why they'll make a full recovery – apart from the dignity bit.

12 DECEMBER

The Woman Raised By Monkeys

National Geographic, 12 December, 9pm



KIDNAPPED AS A four-year-old child in 1954, Marina tells an extraordinary story of waking up alone in the Colombian jungle and being adopted by a troop of capuchin monkeys. For five years they looked after her as if she was their own, grooming her, protecting her and probably saving her life. What were the long term effects on her development? Apart from leaving her with the domestic standards of the average UK university student, that is...

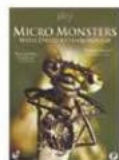
DVD AND BLU-RAY



Mankind: The Story Of All Of Us

Warner Home Video, £6.99

THIS 12-HOUR series tells the story of how humans grew from tribes of hunter-gatherers into vast civilisations. Whether it was Rome's military machine, or the machinery of the Industrial Revolution, each episode explores the key ideas that helped people prosper.



Micro Monsters 3D

Go Entertain, £13.30

THIS DAVID ATTENBOROUGH series peers into the deadly, disgusting adaptations insects and arachnids have evolved in glorious 3D. Meet beetles that squirt out boiling chemical cocktails, and bugs that wear the corpses of their victims. It's also available on DVD in two dimensions.



The Right Stuff

Warner Home Video, £12.39

KNOW SOMEBODY WHO'S crazy about space? Make their Christmas with the Blu-ray version of this ambitious movie, adapted from Tom Wolfe's book, that tells the story of aviation pioneers, from Chuck Yeager's breaking of the sound barrier to the selection of the first Mercury astronauts.

9 DECEMBER

Top Ten Natural Disasters

National Geographic, 9 December, 9pm



PUT THE CHAOS of pre-Christmas shopping, the post-office party devastation, and the domestic upheaval of decorating the tree into perspective. Experts armed with CGI and real footage count down the 10 most important natural disasters EVER, in a two-hour special that shows Nature's least appealing face and captures the moments when natural phenomena become human tragedy, sometimes even changing the course of history.

16 DECEMBER

Worst Weather Ever?

National Geographic, 16 December, 9pm



IN THE NORTHERN hemisphere we're bracing for snow, rain, floods and hailstones, while Australia battles bushfires, and typhoons and hurricanes wreak havoc around the world. As the climate changes, is weather getting weirder and wilder? It's a hotly contested topic. Some claim we've always had terrible meteorological events; it's only the fact that we're an advancing civilisation that makes us more aware of it – and the resulting damage more expensive. In this programme, scientists try to unravel the causes and effects.



LISTEN

BBC RADIO PROGRAMMES

WITH TIMANDRA HARKNESS

FROM 18 NOVEMBER

History Of Britain In Numbers

BBC Radio 4, starts 18 November, 1.45pm (omnibus Friday 9pm)

LIFE EXPECTANCY, AVERAGE earnings, how many children or rotten teeth we have: statistics can reveal a lot about how we live now – and how we lived in the past. Andrew Dilnot, Chair of the UK Statistics Authority, crunches the numbers to show a different face of Britain's history. He crunches, squeaks, rings and sings the numbers, in fact, bringing graphs and spreadsheets to life in sound like never before on radio.

world? Can we make sense of it fast enough? And what makes Big Data different from old-fashioned statistics? Some woman called Timandra Harkness investigates.



Have the number-crunchers bitten off more than they can chew?

24 & 31 DECEMBER

Shared Planet

BBC Radio 4, 24 & 31 December, 9 pm

TWO SPECIAL EDITIONS of the natural history series that generally gives the human race a weekly ticking-off. Recorded live, with an audience, the Christmas Eve edition is a debate on human population (will they be celebrating the birth of baby Jesus, we wonder?) and New Year's Eve discusses "which wildlife is important?". It's the tastiest ones, isn't it?

WEEKLY

Inside Science

BBC Radio 4, Thursdays, 4.30pm

THE WEEKLY SCIENCE show presented by Dr Adam Rutherford, sometimes replaced by Dr Lucie Green or Prof Alice Roberts, continues to get into its stride. It aims to go behind the scenes of research, bringing the people, the places and even the equipment to you. You'll sometimes be glad they can't yet bring you the smells.

1 DECEMBER

The Next Global Killer

BBC Radio 4, 1 December, 5pm

SWINE FLU, BIRD flu, monkey measles – the deadliest diseases seem to incubate in animal populations before making the jump to become a human epidemic. Science journalist Alok Jha studies the history of 'zoonoses', as they're called, and meets the scientists trying to spot the next culprit before it happens. And no, you're right – monkey measles doesn't exist. Yet.

10 DECEMBER

Data, Data, Everywhere

BBC Radio 4, 10 December, 4pm

BIG DATA IS everywhere, with digital information pouring out of our smartphones, internet searches, medical records and supermarket loyalty cards. Scientific research from CERN to cancer genomics relies on computers crunching trillions of digits. Will it transform our



TOUCH

TABLET & SMARTPHONE APPS

WITH CHRISTOPHER BRENNAN

Spider in da house

iPhone, iPad, iPod touch, Android 2.2 or later
TouchApp Ltd and Society of Biology, free



WHEN FACED WITH a spider in your house the natural reaction can be to swat it with a newspaper or, more humanely, catch it under a glass and return it to the outside world. If you're in the former group, then Spider in da house might be the perfect app for you. The software teaches you how to identify the various spiders that often find their way into our homes and to keep a record of any sightings. The app's authors are hoping to collect enough data to study migration patterns.

Anatomy and Physiology

iPad
Visible Body, free (with in-app purchases)



THIS APP IS an educational tool to help you get a grip on the human body and it goes into incredible detail. There are intricate 3D models of all the body parts that you can zoom and rotate on-screen, so it's perfect if you're taking a biology course. Anatomy and Physiology is free and you get the respiratory system included, but there's a £25 in-app purchase for the other course units, which is a bit on the expensive side for the casual buyer. You can, however, at least try it out for free to see if it's for you.

Mushroom Id

iPhone, iPad
Isoperia, £2.99



MUSHROOM-SPOTTING, THE less trendy version of trainspotting, is just as much fun and doesn't require that you sit on the end of a wet platform in Crewe. This app, as the name suggests, allows you to identify your fungi on a quite epic scale. The app has pictures of all the mushrooms out there with descriptions to help you identify the species you're looking at, and to help you learn a little more about the mushroom family. It's a bit basic, but a useful reference nonetheless.

CHRISTOPHER BRENNAN is a technology journalist and mobile app expert



READ

THE LATEST SCIENCE BOOKS REVIEWED

Hardback Paperback

Just Babies

The Origins Of Good And Evil

Paul Bloom

Bodley Head £16.99

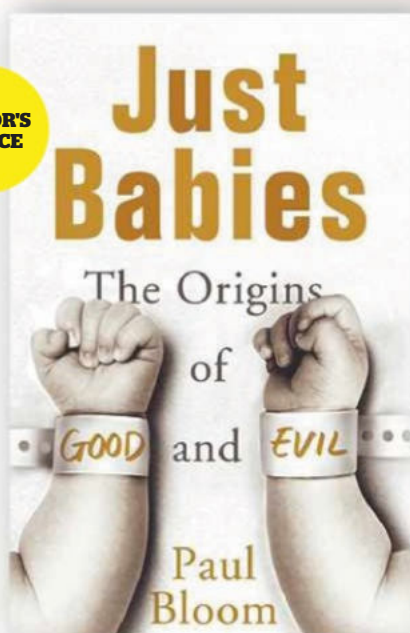
PAUL BLOOM IS a developmental psychologist. That means he studies children and babies to understand how adult faculties develop. In *Just Babies* he takes us on a tour of what developmental psychology can tell us about morality – about why some behaviours are taboo and others are compulsory (and why some of these things vary across cultures).

Bloom's account blends evolved instincts with the vagaries of culture. An example is the notion of disgust. Some objects are disgusting all over the world – things that cause infection such as faeces, pus or other bodily fluids. But the power of disgust to override empathy can also be harnessed by cultures in myriad ways, such as when racial tensions are incensed by describing a particular ethnic group as dirty or unclean.

Studies of children show that the notion of disgust has a particular trajectory; it takes a while to develop. Experiments reveal that children under two will happily eat a faeces-shaped piece of chocolate, whereas adults and older children point blank refuse, even though they fully believe it to be normal chocolate. What counts as disgusting then gets tuned by our experience and applied beyond the realm of potentially infectious objects, being taken up to

“The power of disgust to override empathy can also be harnessed by cultures in myriad ways”

EDITOR'S CHOICE



describe everything from manners to sexual behaviours.

Other fascinating research compares how much babies look at things around a room to infer their expectations and beliefs about how the world works. This shows that even a nine-month-old expects people to approach someone who has previously helped them, and avoid someone who has previously hindered them.

There's too much in Bloom's book to give a full account in this review. Every page sparkles with deep thoughts clearly stated. Throughout, evolution is taken as a fundamental principle, developmental psychology is the method, and culture is the riddle.

Bloom argues that we are born with moral instincts and these are shaped by reason and culture, so over time our morals themselves evolve. This is witnessed by changes in attitudes to homosexuality, women's dress codes and food customs.

He is an author that you would want to spend time with – a funny, generous, dedicated scientist who has sympathy for the full range of human hopes and pains.



TOM STAFFORD is a psychologist and the co-author of *Mind Hacks*

MEET THE AUTHOR



Paul Bloom

Why did you decide to write the book?

It put together two of the things that interest me most: child development and human morality. I'm just fascinated by the question of what it's like to be a baby or a young child, and I'm also fascinated by good and evil. Why is it we view some things as right and wrong – where do these moral feelings come from?

So what gives us our sense of morality – do we all begin life as blank moral slates?

No – I think we're wired up to be moral beings from the very start. We know that babies have a degree of moral understanding. We do these 'puppet show' experiments where they see 'good guys' and 'bad guys' who are helping or hindering each other. Babies actually prefer the one who helps, and later on they'll reward good guys and punish bad guys. So a substantial amount of morality is hardwired from a very young age.

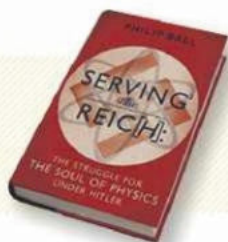
Why is so much of our morality hardwired?

Over the last 100 years, scholars have figured out how Darwinian biological evolution can actually give rise to creatures who are altruistic, kind and moral. Part of the idea here was nicely spelt out by Richard Dawkins in *The Selfish Gene*: if you assume that genetic evolution is, in a sense, for the benefit of the gene, that actually means you tend to be kind to others who share your genes. On top of that, if you have repeated positive interactions with another individual, both of you will be better off. But evolution doesn't explain everything – certain moral insights are a product of culture, development and reason.



MORE ON THE PODCAST

Listen to the full interview with Paul Bloom at sciencefocus.com/podcasts



Serving The Reich

The Struggle For The Soul Of Physics Under Hitler

Philip Ball
Bodley Head £20

HOW MUCH CAN science remain aloof from the pressures of society? For the physicists of 1930s Germany, the question could be literally a matter of life or death, as Philip Ball's fascinating new book explores. Taking inspiration from the story of Peter Debye, a pioneer of physical chemistry who was recently denounced as an opportunist who curried favour with the Nazis, Ball sets out to uncover a far more nuanced story of science in turbulent times. Meticulously researched, the book focuses on three key figures – Debye and the better-known names of Max Planck and Werner Heisenberg.

None of these men showed any admiration for national socialist ideology, but all eventually came to compromise with their political paymasters. In their attempts to tread the middle path between self-preservation and complicity, Ball's central trio suffered attacks from all sides.

Despite the book's approachable text, its exploration of a troubled period may not be for everyone. Nevertheless, it carries an important warning about the moral hazards implicit in burying one's head in scientific theory and distancing oneself from the world's messy realities.



GILES SPARROW is a space and astronomy writer and author of *The Cosmic Gallery*



Imagine That...

The History Of Technology Rewritten

Michael Sells
Icon Books £6.99

THERE'S A WORLD in which this is a well-written collection of brief essays about the points where the world changed, when a single ignored petri dish or bad business decision cast us into an alternative universe without Facebook, penicillin or mobile phones.

Sadly we're not living in that particular branch of the multiverse. Instead we've got a fairly random set of stories covering topics such as transistors, X-rays, pacemakers, mobile phones and Tesla's 'World System', written in a breezy, cliché-filled style that too often oversimplifies or misleads, and is rarely entertaining or informative enough.

While the choice of topics looks interesting – though calling the antibiotic penicillin a 'technology' seems to be a bit of a stretch – the speculation about what might have happened if the world had been different is sometimes absent. We hear about Wilson Greatbatch's work on pacemakers and Percy Shaw's invention of the cat's eye, but there's nothing about the world without them. And if Mark Zuckerberg had abandoned Facebook at college, apparently another 'supergiant' would probably have replaced it.



BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service



The Nostalgia Factory

Memory, Time And Ageing

Douwe Draaisma
Yale University Press £16.99

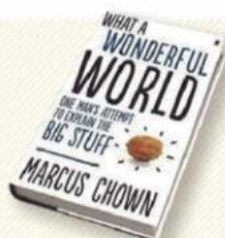
IF YOU'RE OVER 30 the chances are that you have already experienced the events that you will later describe as the most exciting things that have happened to you. No matter that you have yet to meet the love of your life, win a Nobel prize or take a trip to the Moon. In old age the memories laid down in what psychologists call the 'remembrance bump' – a crucial period between about 15 and 30 – will probably be brighter than your recollection of that day's breakfast.

Douwe Draaisma, Professor of the History of Philosophy at the University of Groningen, ponders this weird aspect of memory in his short but resonant book. Perhaps, he says, our brains evolved to hold on to events that occurred before our offspring's time primarily in order to tell them about it. Before the written word, such stories would have been the main way of passing on information.

Full of intriguing information and touching interviews, *The Nostalgia Factory* may help you to hear Grandpa's rambling war stories in a different way. It may also stop you mourning your past youth – soon, it reminds you, you'll be able to live through it all over again.



RITA CARTER is a science writer and author of *Mapping The Mind*



What A Wonderful World

One Man's Attempt To Explain The Big Stuff

Marcus Chown
Faber and Faber £17.99

THE UNIVERSE IS big and unwieldy and generally doesn't like being confined to nutshells. Not to be put off however, cosmologist and writer Marcus Chown has set himself the daunting challenge of concisely explaining science's big subjects – from biological first principles to the more esoteric areas of physics and cosmology with 'everything else' in between.

The problem is that many of these subjects stubbornly resist being explained; we rely on human-scale analogies to explain mind-boggling concepts. That aside this is an admirable attempt, particularly with such a wide range of subjects: genetics, geology,

neuroscience, computer science and more. It's thorough, clear, and lively as Chown's books always are. He relies on the help of other scientists and writers to prop it up, with quotations from Dawkins, Feynman, Jared Diamond and Adam Rutherford, but as a volume with such ambition it lacks that goose-bump inducing sense of poetry. It might be a wonderful world, but freeing that sense of wonder from the dense jungle of explanations can be a tough nut to crack.



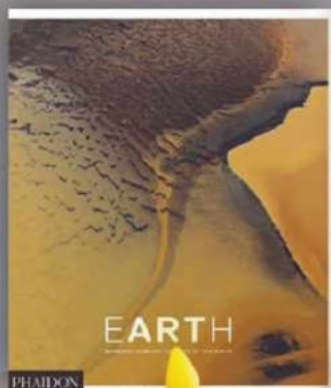
DALLAS CAMPBELL is a BBC TV presenter whose shows include *Supersized Earth*



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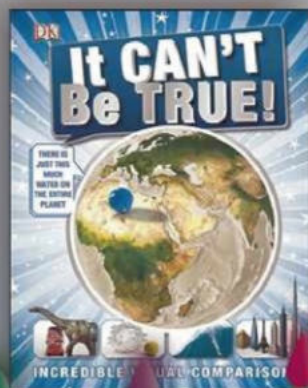
Hardback Paperback



Earth

Bernhard Edmaier
Phaidon £39.95

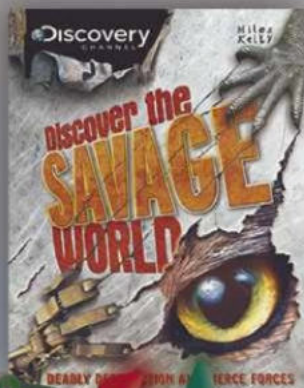
This lavish coffee table book showcases Earth's beauty from the air. Its brief but informative captions explain how islands, glaciers and volcanic eruptions were formed. Simply stunning.



It Can't Be True!

Ed. Rob Houston
DK £12.99

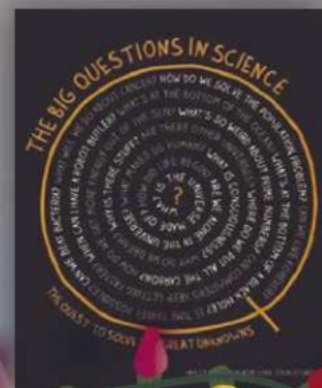
With top-notch visuals on every page, this book reveals some fascinating comparisons. Quahog clams can live for 405 years – twice as long as a bowhead whale. Who knew?



Discover The Savage World

Miles Kelly
Discovery Channel £20

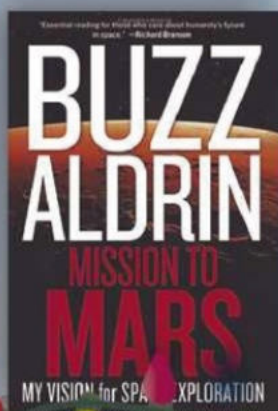
Kids will love this exploration of extremes. From deadly insects to the planet's biggest ships and planes, the facts keep coming.



The Big Questions In Science

Hayley Birch, MK Looi, Colin Stuart
Andre Deutsch £14.99

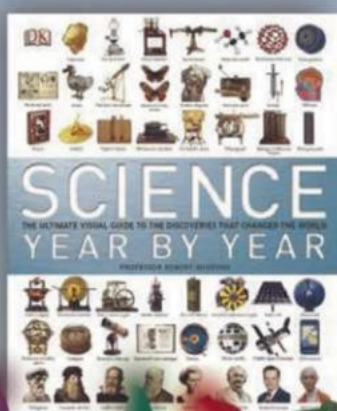
Can we live forever? How did life begin? Is time travel possible? This book attempts to answer 20 of the biggest science mysteries.



Mission To Mars

Buzz Aldrin
National Geographic £19.99

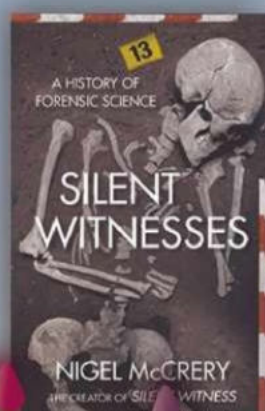
The second man on the Moon sets out his inspiring vision of how we can get to Mars – and what we should do when we get there.



Science Year By Year

Ed. Prof Robert Winston
DK £25

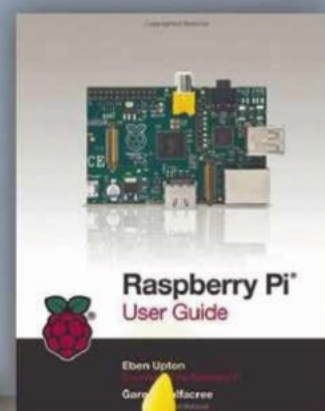
This comprehensive reference book begins 2.5 million years ago with stone tools, and ends with stem cells being injected into brains. Indispensable.



Silent Witnesses

Nigel McCrery
Random House £18.99

Fan of *Sherlock Holmes* and *CSI*? This history of forensic science, written by the man behind *Silent Witness*, gives you the facts behind the fiction.



Raspberry Pi User Guide

Gareth Halfacree and Eben Upton
Wiley £12.99

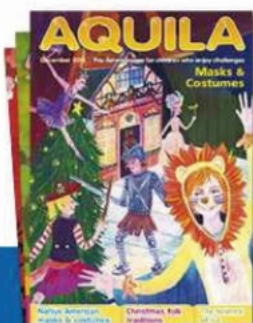
There are now over a million Raspberry Pi owners. If you're one of them, this handy reference guide tells you how to use your Pi and ideas of what to do with it.

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These miniature 3cc V-Twin combustion engines run off butane or propane gas. They are small enough to run on your desk and have an awesome v-twin sound. Just turn the valve and flick the flywheel to get it started.



This Vulcan stove fan is driven using Stirling engine technology using just the heat from a stove. It requires no external power source such as batteries or AC power. The fan circulates the stove's warmth quietly, efficiently and inexpensively.



Newly invented, this tractor beam magnet contains a number of magnets in a special arrangement. The special arrangement creates a unique magnetic field that can hold another magnet a fixed distance away.



This is a Hero Steam turbine. Syringe in some water. Fill the burner with methylated spirits and light it. Moments later you have a steam turbine running. Two tiny jets of steam coming out of the side of the brass ball spins it up to 2500rpm.



These are highly polished solid metal flip over tops. They have a chrome like finish and are excellently machined. Simply spin it as normal and watch it suddenly flip over and then continue to spin upside-down.



Ferrofluid is a runny fluid that is magnetic. Hold a magnet to it and watch how it reacts. Some of the shapes you are can create are mesmerizing.

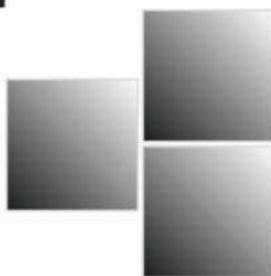
MINDGAMES



Pit your wits against these brainteasers by David J Bodycombe, question-setter for BBC Four's *Only Connect*

PRIZE PUZZLE

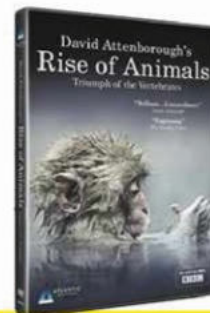
Each square tile is touching two other tiles. How many identical square tiles would you need in total if each one touched exactly four other tiles along its edges?



WIN! DAVID ATTENBOROUGH'S RISE OF ANIMALS - TRIUMPH OF THE VERTEBRATES

The first five correct entries win a copy of *Rise Of Animals* on DVD (BBC, £12.42).

Post your entry, marked 'Prize Puzzle 262', to: *BBC Focus Magazine*, PO Box 501, Leicester, LE94 0AA, to arrive by 5pm on 12 December 2013. We regret that we cannot accept email entries for this competition. See sciencefocus.com/winners for a list of previous winners and solutions.



See bottom of p30 for terms and conditions. Congratulations to Chris Coghill, Oxford, who answered September's Prize Puzzle correctly to win a copy of *Particle Physics: A Graphic Guide* by Tom Whyntie.

Q1

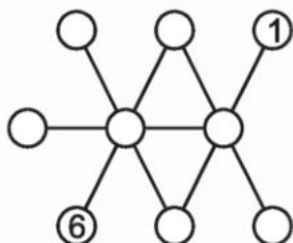
What connects the indigestible gills of a crab, a train safety feature, the foxglove, Aces and 8s, and a song in *Treasure Island*?

Q2

Which word reads the same forwards, backwards or turned upside down?

Q3

Complete the diagram with the remaining digits from 1 to 9 so that each of the five straight lines add up to 18.

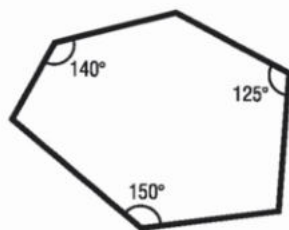


Q4

In order of seniority, black, violet, red and white caps are worn by whom?

Q5

What is the total of this shape's internal angles?



Q6

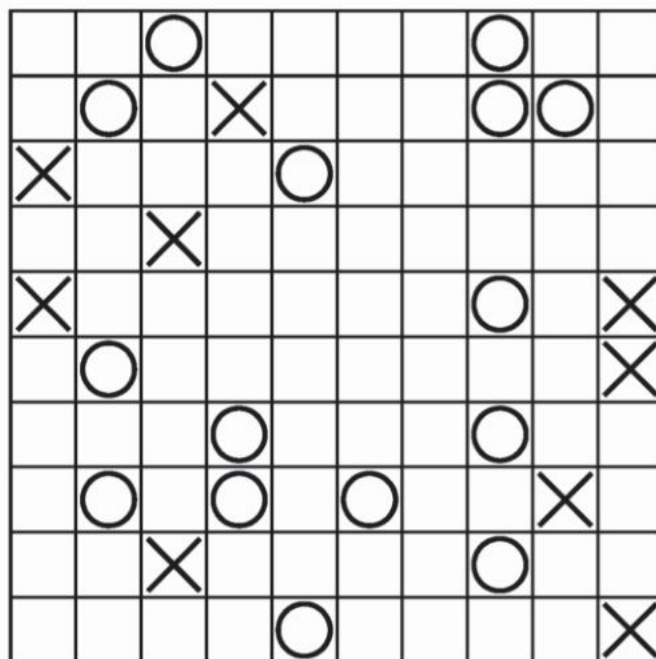
235951 is the highest prime number you could read on what device?

Q7

Given that something different comes fourth, what completes the sequence WWYAMC, WWYAMC, WWYAMC, ?

Q8

Each row and column contains five O and five X. In addition, there is never a run of three O or three X consecutively, horizontally or vertically. Complete the grid.



SOLUTIONS

(Q6) A six-digit, 24-hour clock (23 59 51).
(Q7) AAHNY (We Wish You A Merry Christmas (x3), And A Happy New Year).
(Q8) See illustration at the bottom of p30.

(Q5) Any convex hexagon, regardless of whether the sides or angles are equal, has internal angles of 720°.
(Q4) Cardinals and the Pope.
(Q3) Top row: 3, 5, 1; middle: 2, 7, 9; bottom: 6, 8, 4.

(Q4) Catholic clergy - they are the zucchetto worn by priests, bishops.

(Q1) Dead man: Dead man's fingers, dead man's hand and 'Dead Man's Chest'.
(Q2) NOON

QUICK QUIZ

Test your knowledge of the electromagnetic spectrum

Q1

Which type of radiation has the shortest wavelength?

- a) Gamma rays
- b) Ultraviolet
- c) X-rays

Q2

How fast do electromagnetic waves travel in a vacuum?

- a) 299,792m/s
- b) 299,792,458m/s
- c) 299,792,458,286 m/s

Q3

Visible light is situated between which regions of the spectrum?

- a) Ultraviolet and near-infrared
- b) X-rays and ultraviolet
- c) Near-infrared and microwave

Q4

Physicist Wilhelm Röntgen is credited as the discoverer of which type of radiation?

- a) X-rays
- b) Infrared radiation
- c) Radio waves

Q5

Which of these types of radiation will the James Webb Space Telescope be detecting?

- a) Radio waves
- b) X-rays
- c) Infrared radiation

Q6

Which colour of visible light has the longest wavelength?

- a) Blue
- b) Green
- c) Red

Q7

Which type of radiation is used for long distance broadcasts?

- a) X-rays
- b) Radio waves
- c) Microwaves

ANSWERS:

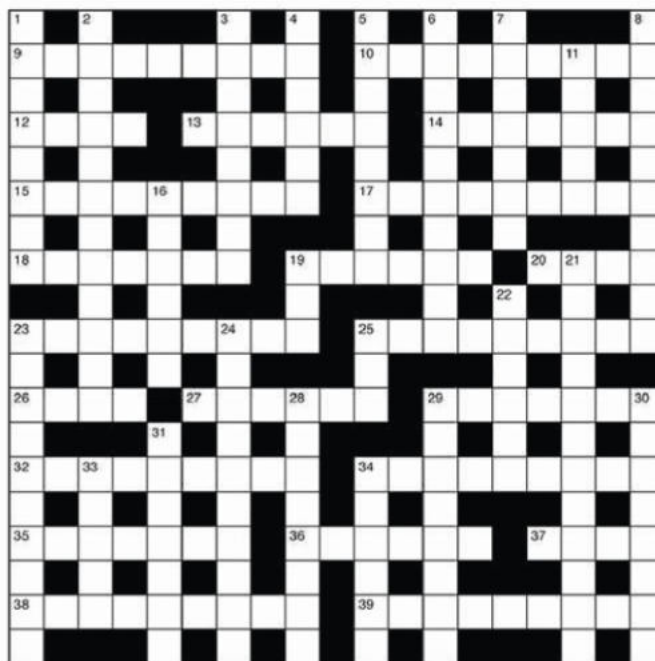
1a, 2b, 3a, 4a, 5c, 6c, 7b

YOU ARE:

- 0-3 X-rated
- 4-5 Radiating energy
- 6-7 Off the spectrum

FOCUS CROSSWORD No 158

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ACROSS

- 9 Use steel to manage an optical device (9)
- 10 Organ acquires clean condition (9)
- 12 The burden we bear (4)
- 13 Aristotle's school solved my clue (6)
- 14 Ivy, say - the mountaineer (7)
- 15 Nice term spent with new supplement (9)
- 17 Get ashpit prepared for food (9)
- 18 Former spouse gets generous specimen (7)
- 19 Land that computers have a name for (6)
- 20 Sailor finds new lake (4)
- 23 Wrong, because so greasy (9)
- 25 Revolutionary rum brewed by soldier caught using organic material (9)
- 26 Run up, right to left, getting a stitch (4)
- 27 Crocodile with its own islands (6)
- 29 Let's hit out at a national symbol (7)
- 32 Throwing robins out, being pushy (9)
- 34 Herb accompanying a port (9)
- 35 Help a plan with kiss on a copy of the Old Testament (7)
- 36 Credit a doctor with old word game (6)
- 37 Confucius ate seaweeds (4)
- 38 Entering a variety of fruit (9)
- 39 Adjusted tie behind terribly remote alien object (9)

DOWN

- 1 Alkaloid may rot a developing tree (8)
- 2 Obscure room found for particle detector (5,7)
- 3 College has information on energy of hereditary material (8)
- 4 Abandon in the Gobi, say (6)
- 5 Send a mob to find a whole bit of a stomach (8)
- 6 Her cicadas thrived on sugar (10)
- 7 Awareness is within view (7)
- 8 Unexpectedly icier month required hot valve (10)
- 11 Scope of morning section (5)
- 16 Require to cough up more than half (6)
- 19 Basic program from Spanish couple (3)
- 21 Ignorant must improve a tiny bit (8,4)
- 22 Group of miners sent Ian some Roman spirits (6)
- 23 Perhaps toy was manufactured at the plant (10)
- 24 Old calix affected by sharp bleach (6,4)
- 25 Tin from Tuscany (3)
- 28 Mother takes recess with eastern heretic (8)
- 29 A better solution with variable amount of memory (8)
- 30 Inspector, formerly a collier (8)
- 31 Ambush black plane (4,3)
- 33 Poison not working with cricket team (5)
- 34 Tenor with a strange exterior gets a shock (6)

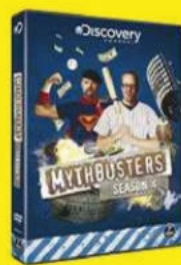
SOLUTION TO CROSSWORD No 155

Andrew Anderson, Penny Fearson, J Walsh, J Bainbridge and John Harvey solved issue 259's puzzle and each receive a copy of *MythBusters Season 1* on DVD.



WIN MYTHBUSTERS SEASON 4 ON DVD

The first five correct solutions drawn will each win a copy of *MythBusters Season 4* (Discovery Channel, £18.90). Entries must be received by 5pm on 12 December 2013. See below for more details.



YOUR DETAILS

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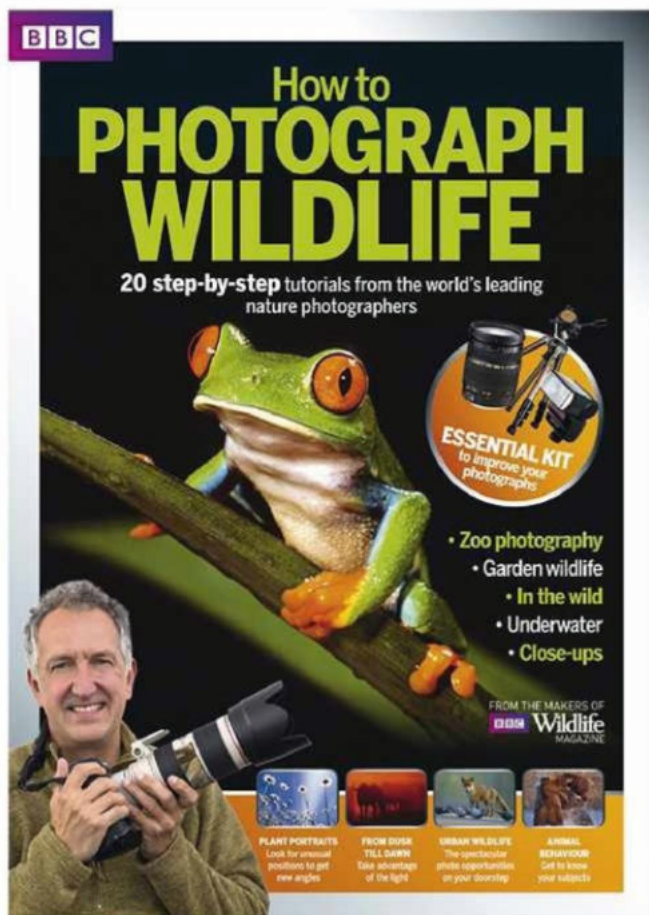
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Post entries to BBC Focus Magazine, December 2013 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to december2013@focuscomps.co.uk by 5pm on 12 December 2013. Entrants must supply name, address and phone number. By entering, participants agree to be bound by the terms & conditions, printed in full on p30. Immediate Media, publisher of *BBC Focus Magazine*, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

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HOLLYWOOD SCIENCE

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Separating science fact from movie fiction

STAR TREK INTO DARKNESS

HERE'S SOMETHING YOU don't see every day. Nappy-wearing, clay-faced aliens gawp open-mouthed as the USS Enterprise rises from its parking space on the ocean floor, hovers in front of their disbelieving eye-holes, then climbs into the sky and finally streaks into space. It's bad juju all round: not just for the hapless spectators who likely fill their nappies and then start to worship said inanimate object, but also for the laws of physics, which are left weeping in a corner.

The ocean floor is no place for a craft designed to swagger in the pressure-free vastness of space. The submarine Deep Sea Challenger, which last year travelled 11km down to the bottom of the Mariana Trench, encased its captain (*Titanic* and *Avatar* director James Cameron) in a 64mm-thick steel sphere, wrapped in high-tech foam designed to withstand pressures so crushing even Jeremy Paxman would crumble. The Enterprise, with its non-spherical hubcap of a hull, would be squidged to oblivion.

As the Enterprise floats to the surface, there's

"It's bad juju all round: not just for the hapless spectators, but also for the laws of physics"

a different challenge to overcome – getting into the air and beyond. There's no runway, no wings to generate lift and, at heights over 12km the air is too thin (on Earth) to keep most planes up. "The only way to overcome these problems is with brute force," says hypersonic aerodynamics expert Leon Vanstone from Imperial College London.

Strapping a rocket on should do the trick, but it'd have to be a whopper. Fifty-tonne Trident ballistic missiles make the leap from underwater to low Earth orbit by using a solid propellant rocket. But the Enterprise weighs around 3.25 million tonnes: assuming no friction, it would need a blast equivalent to 100,000 tonnes of TNT or six Hiroshima bombs to raise it out of the water and into space. "And even that's likely to be a vast underestimate,"

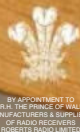


says Vanstone. "The problem is putting all the technology together into one vehicle. The craft we design are optimised for one environment." Spacecraft may be up there with the stars but they can't get down with the fishes. Spaceships, like so many men, are hopeless at multi-tasking.

Perhaps an Enterprise built from some high-tech material would do the trick? Forget graphene, there's a new 'supermaterial' on the block. Carbyne, another carbon-based nano-structure, is thought stronger and stiffer than its rival. So could it make the perfect spaceship? Not only were tiny carbyne chains made in the lab a few years ago, but astronomers think they have detected its signature in space. So perhaps someone's got there before us. ■

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